Jet commissioning in CMS with 900 GeV pp collisions
&
early Physics prospects with Jets

XXVIII Workshop
on Recent Advances in Particle Physics and Cosmology
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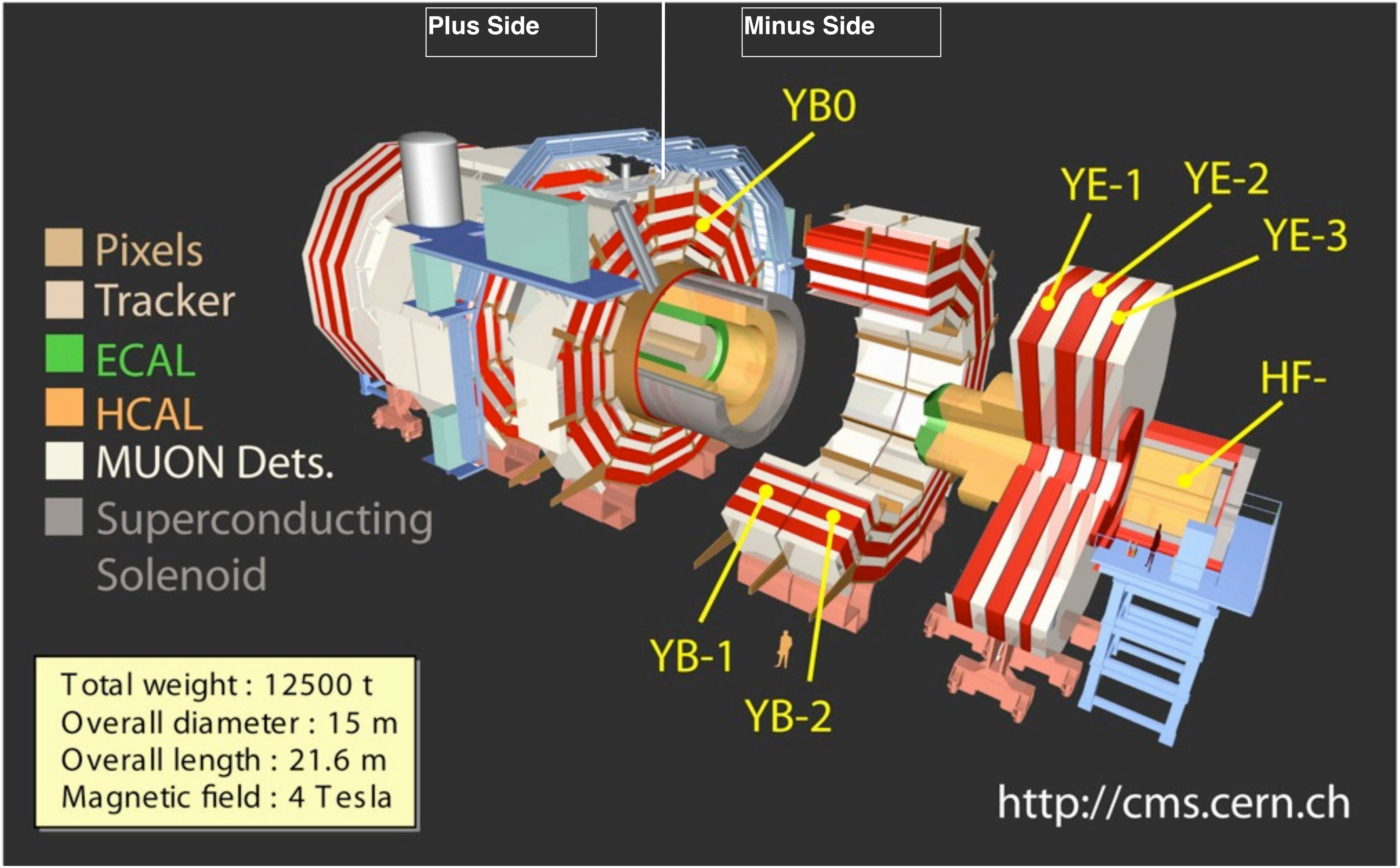
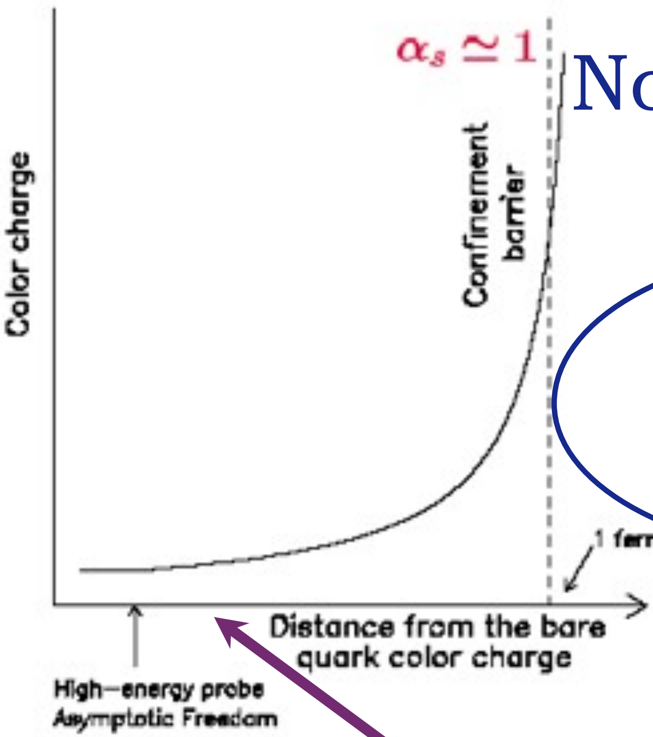
Outline

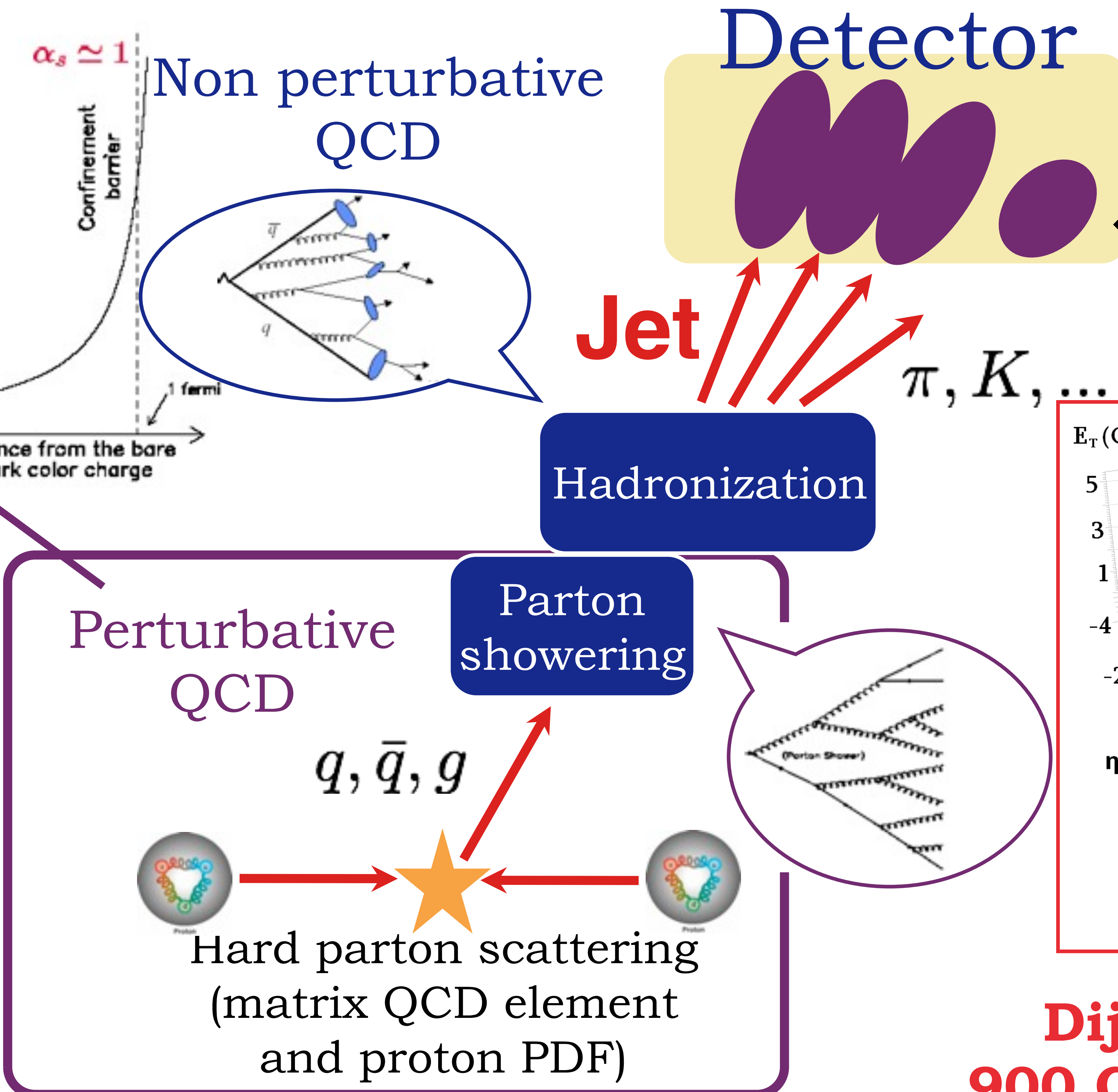
- Jet reconstruction in CMS
  - calorimeter jets
  - jets-plus-tracks
  - particle flow jets
- Jet energy calibration
- Jet commissioning results from 900 GeV and 2.36 TeV pp collisions
- Physics prospects with jets

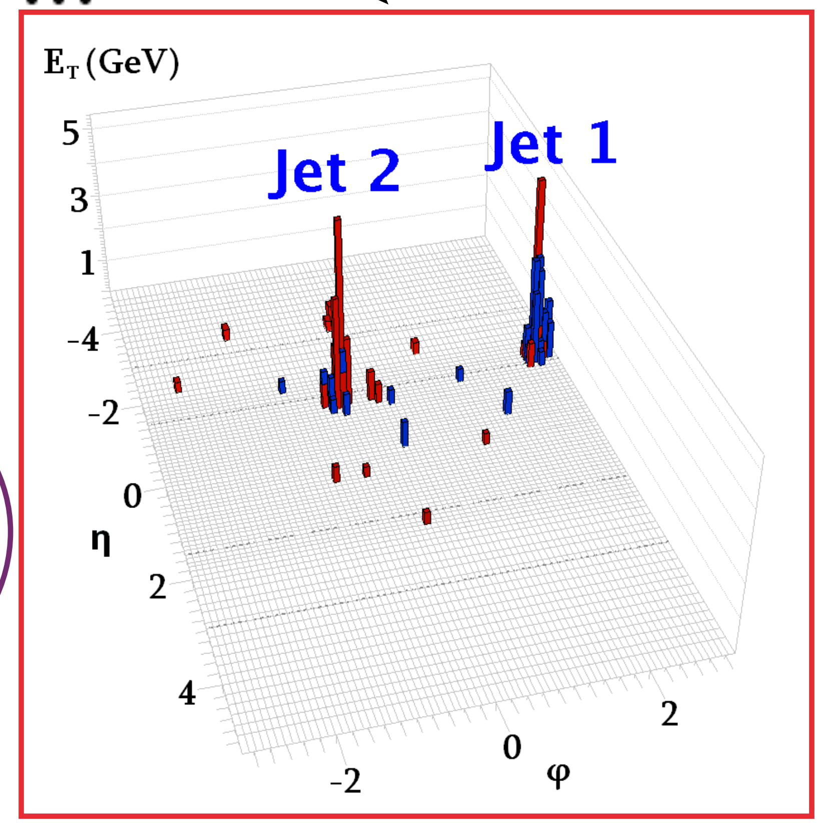
The CMS detector



The jet object

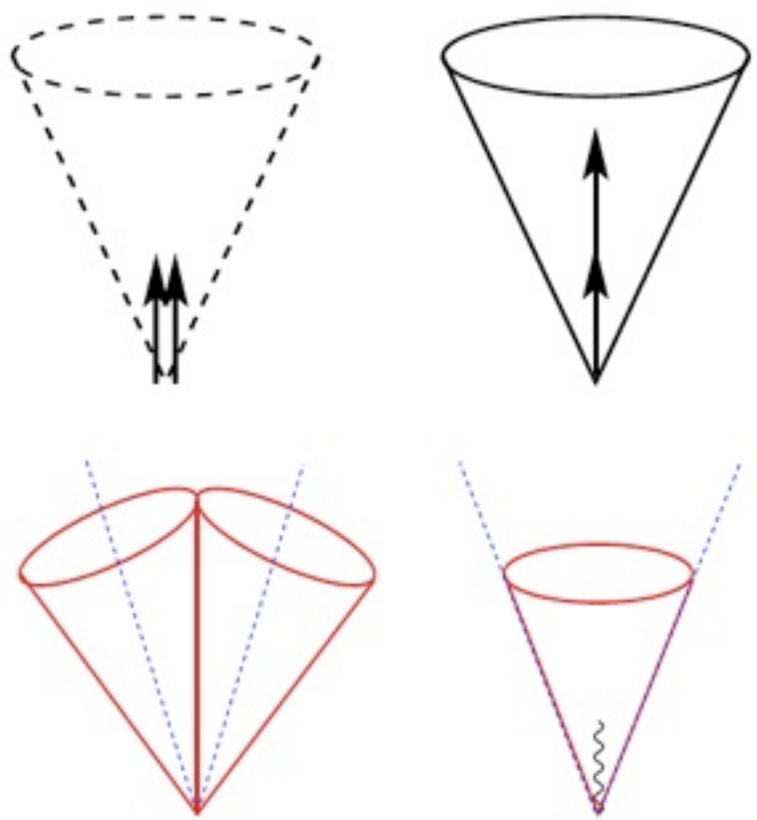






Dijet event from 900 GeV pp collisions

Jet clustering



➡ All jet clustering algorithms in CMS are applied on the 4-vectors of the constituents, regardless of the detector input.
➡ Jets in CMS are massive by construction.

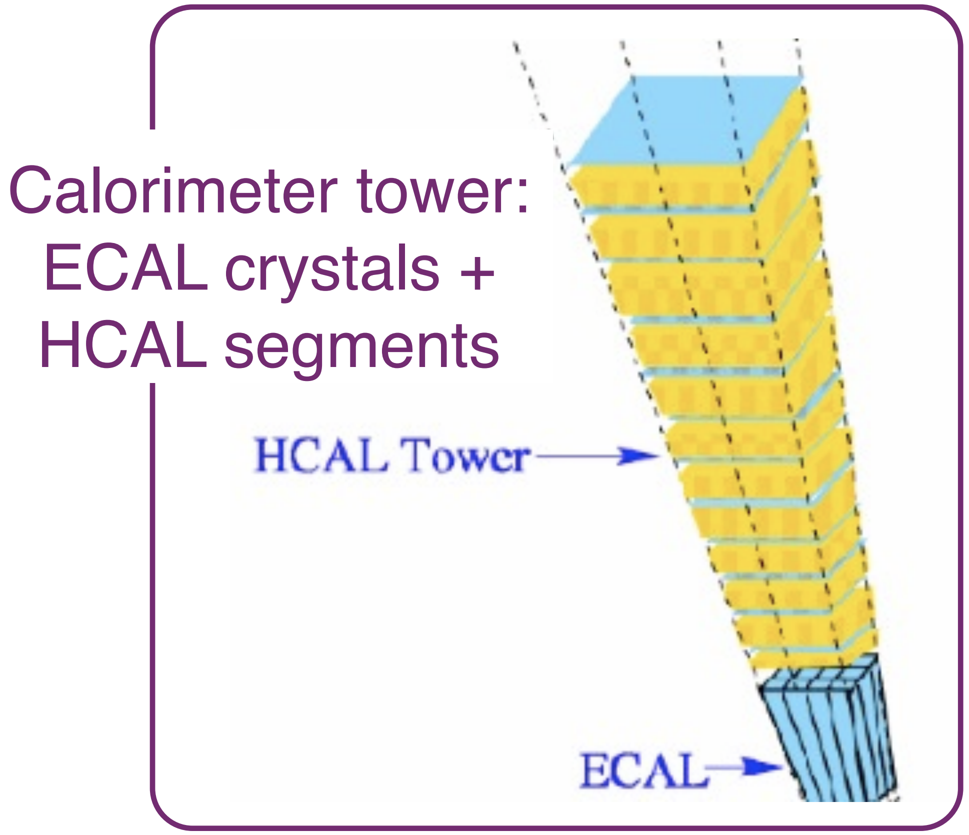
Principles of jet clustering

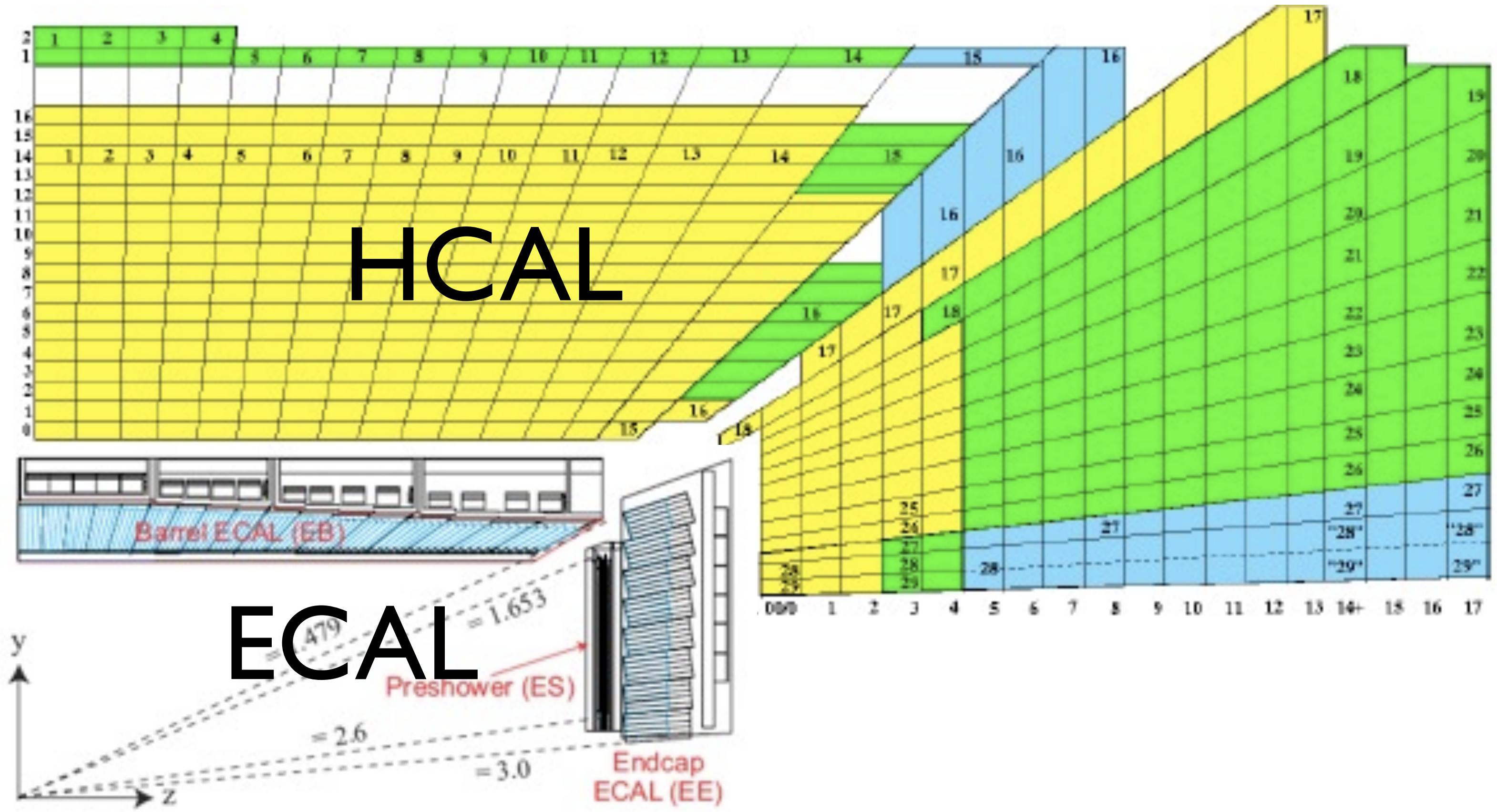
- simplicity
- collinear safety
- infrared safety
- robustness against pile-up and underlying event contamination

Jet clustering algorithms in CMS

- **fixed cone**
  - iterative cone (used for triggering purposes)
  - seedless infrared safe cone (time consuming with pile-up)
- **successive recombination** (clustering based on the p_T weighted distance in y-φ plane between the constituents)
  - k_T
  - anti-k_T (behaves like a fixed cone algorithm)

Calorimeter jets



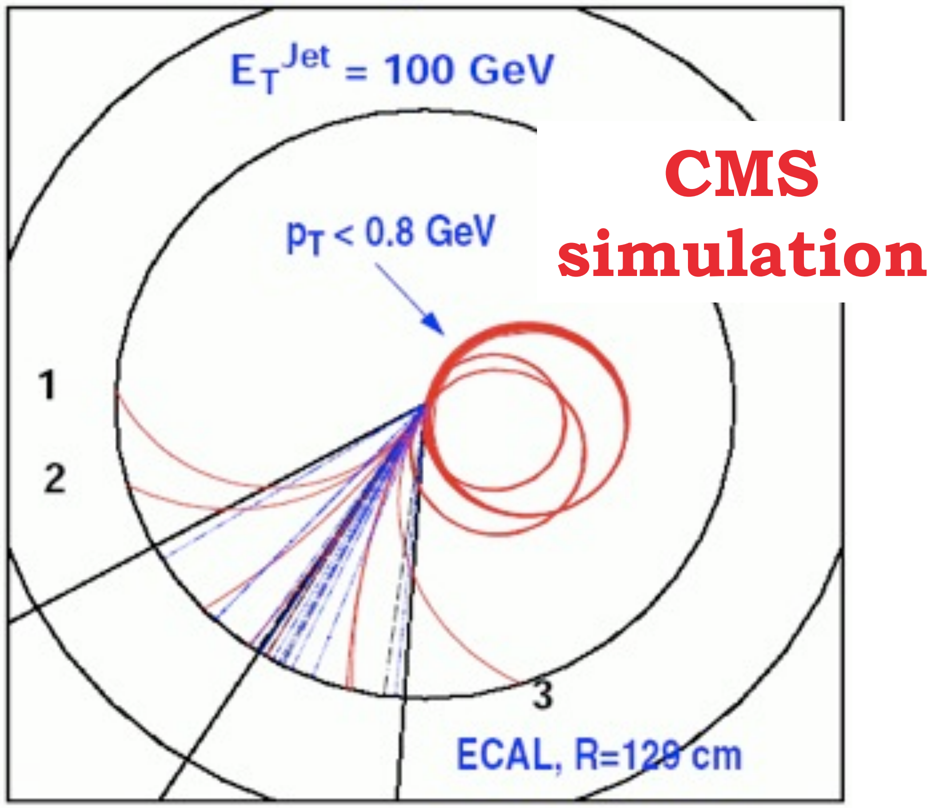


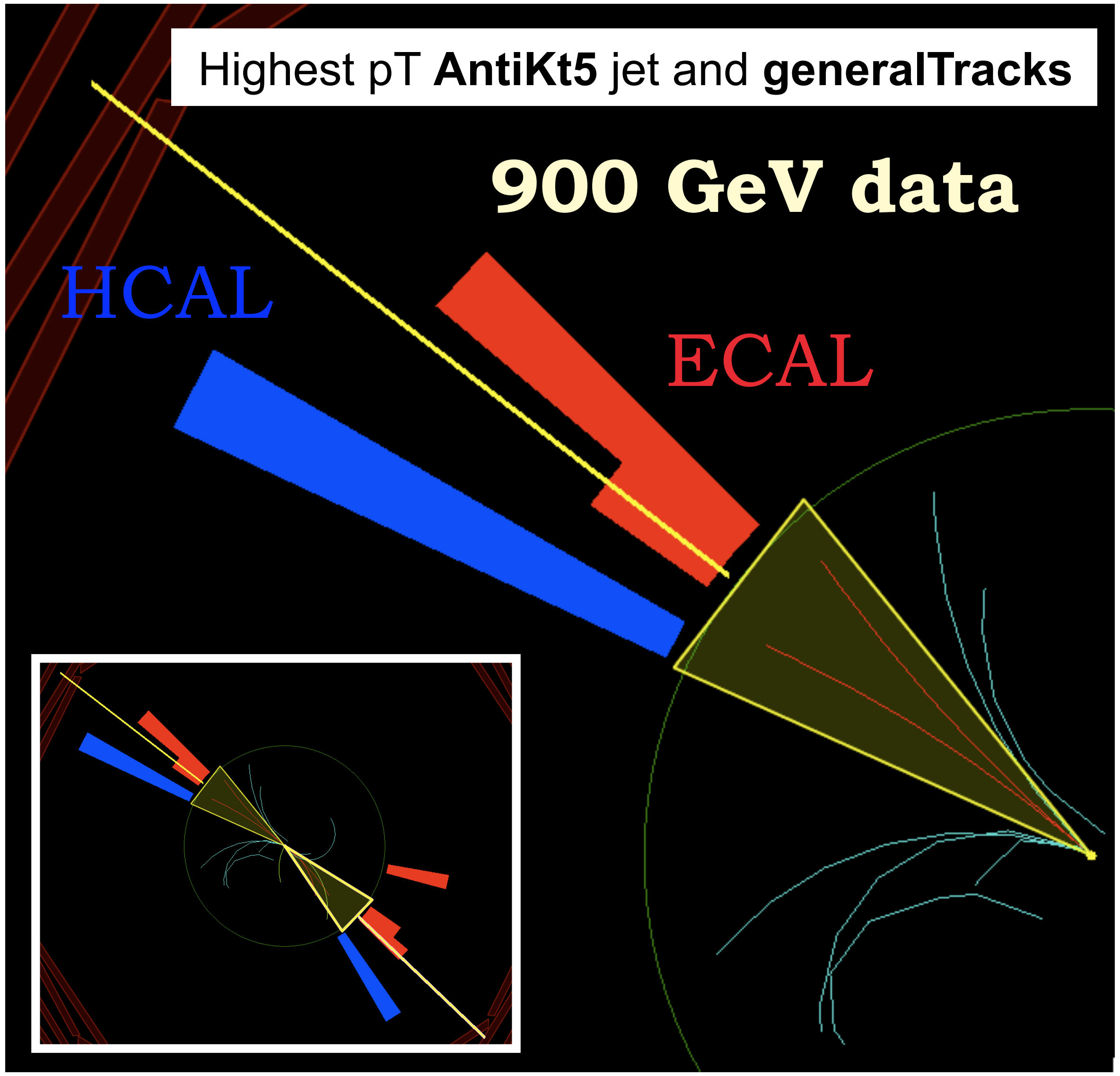
✦ The electromagnetic (ECAL) and hadron (HCAL) calorimeters are the principal instruments to measure jets

✦ HCAL cells and ECAL crystals are organized in projective calorimeter towers

✦ Calorimeter jets are formed by clustering the 4-vectors of calorimeter towers

✦ Due to the non-compensating nature of the CMS calorimetric system, the jet energy response is highly non linear



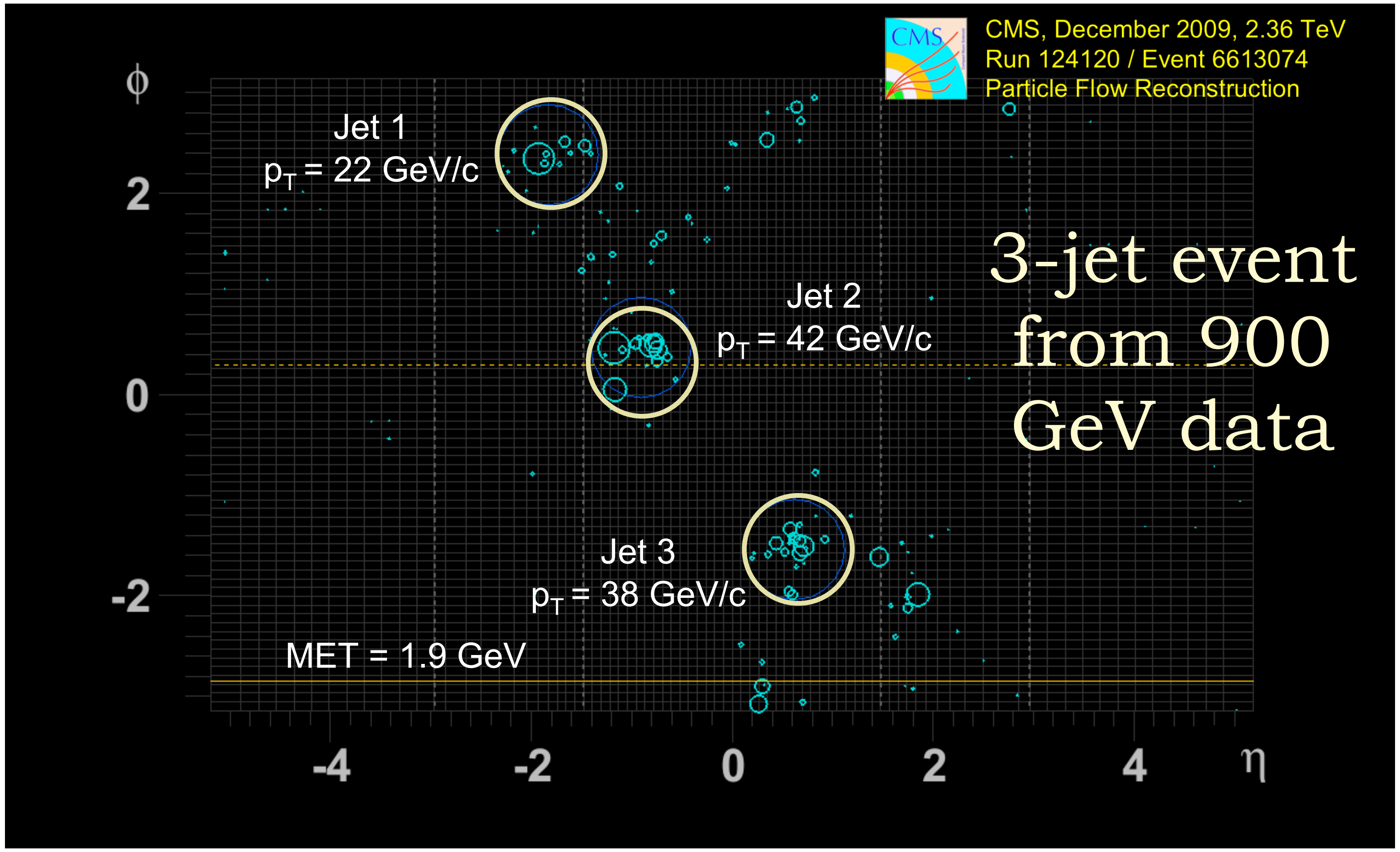


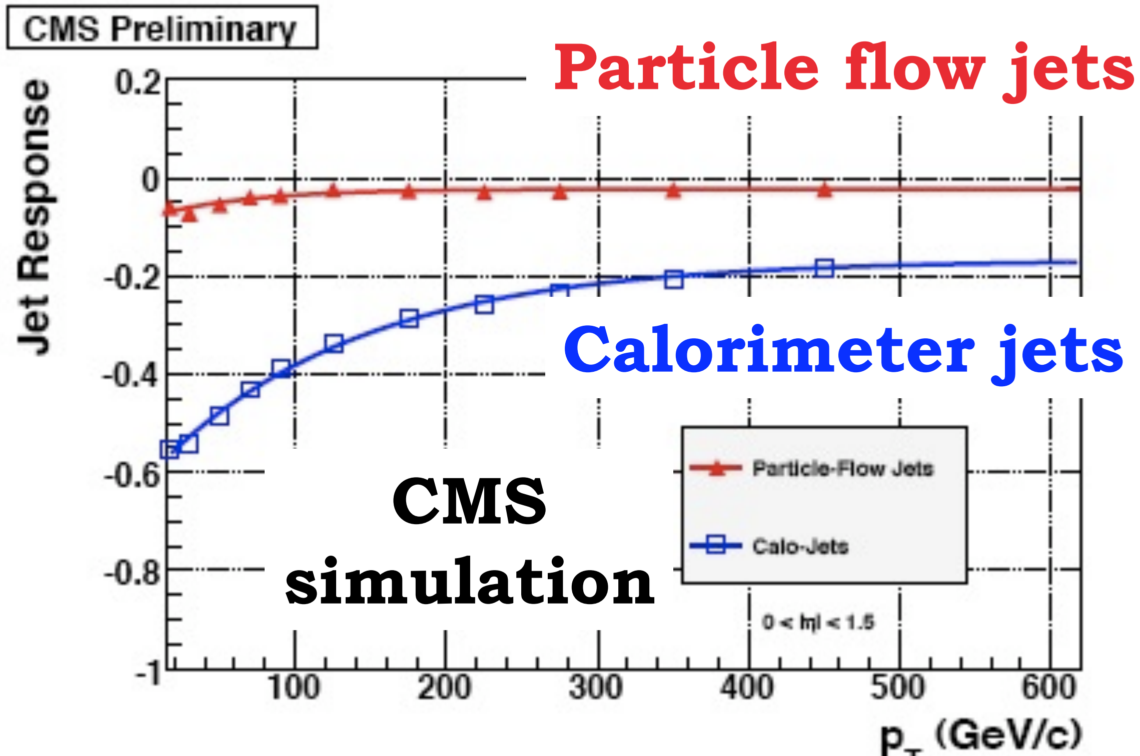
Dijet example from real data

	Jet1	Jet2
Raw p_T	11.6	10.5
JPT p_T	25.8	18.7

- ✦ The Jet-plus-tracks algorithm starts with a reconstructed calorimeter jet and improves its energy and direction measurement by tracker information
- ✦ The momentum of "out-of-cone" tracks is added to the jet energy
- ✦ The momentum of "in-cone" tracks is added to the jet energy and the average expected calorimeter deposition is subtracted
- ✦ Key element: the single particle response

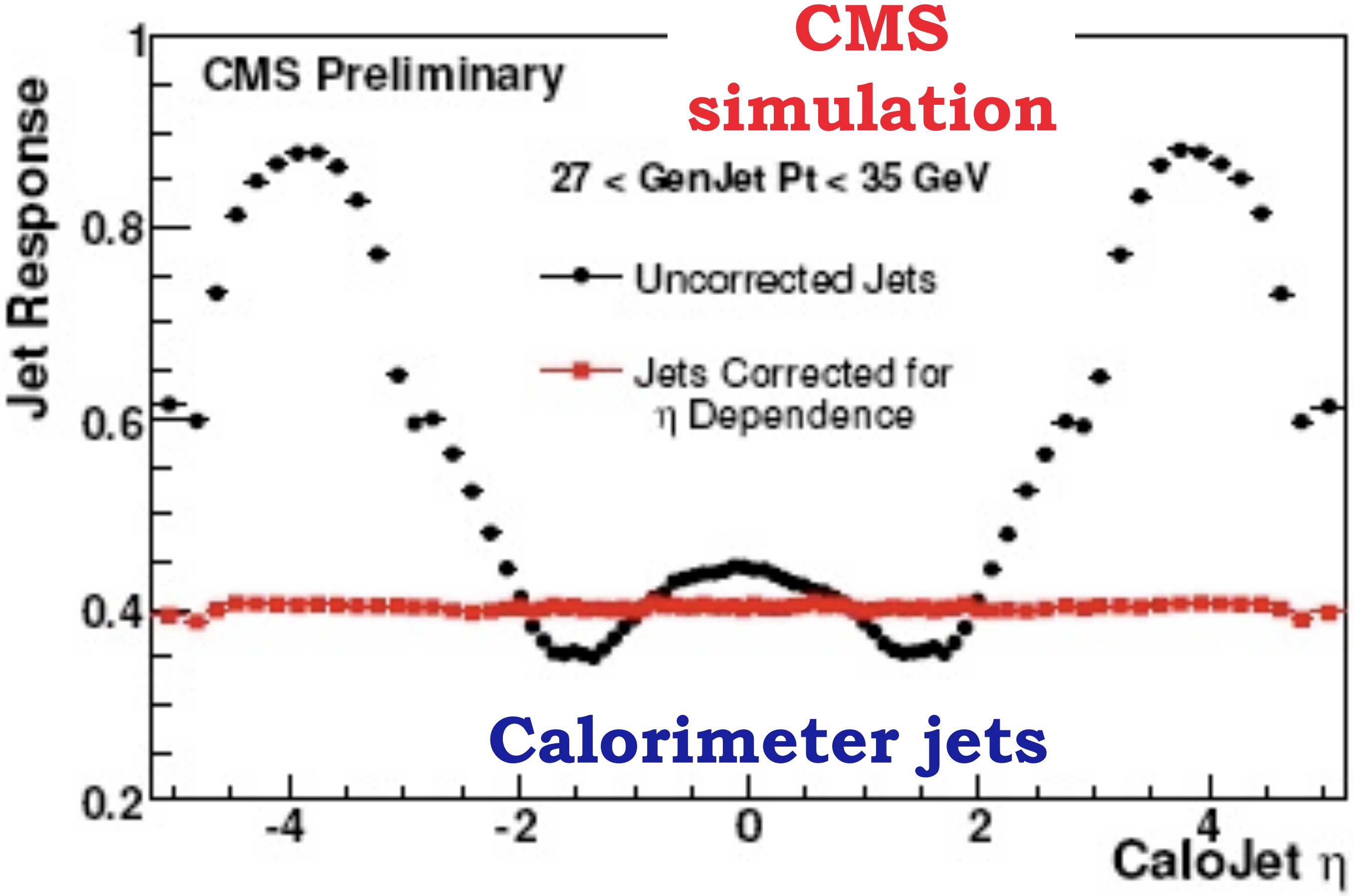
Particle flow jets

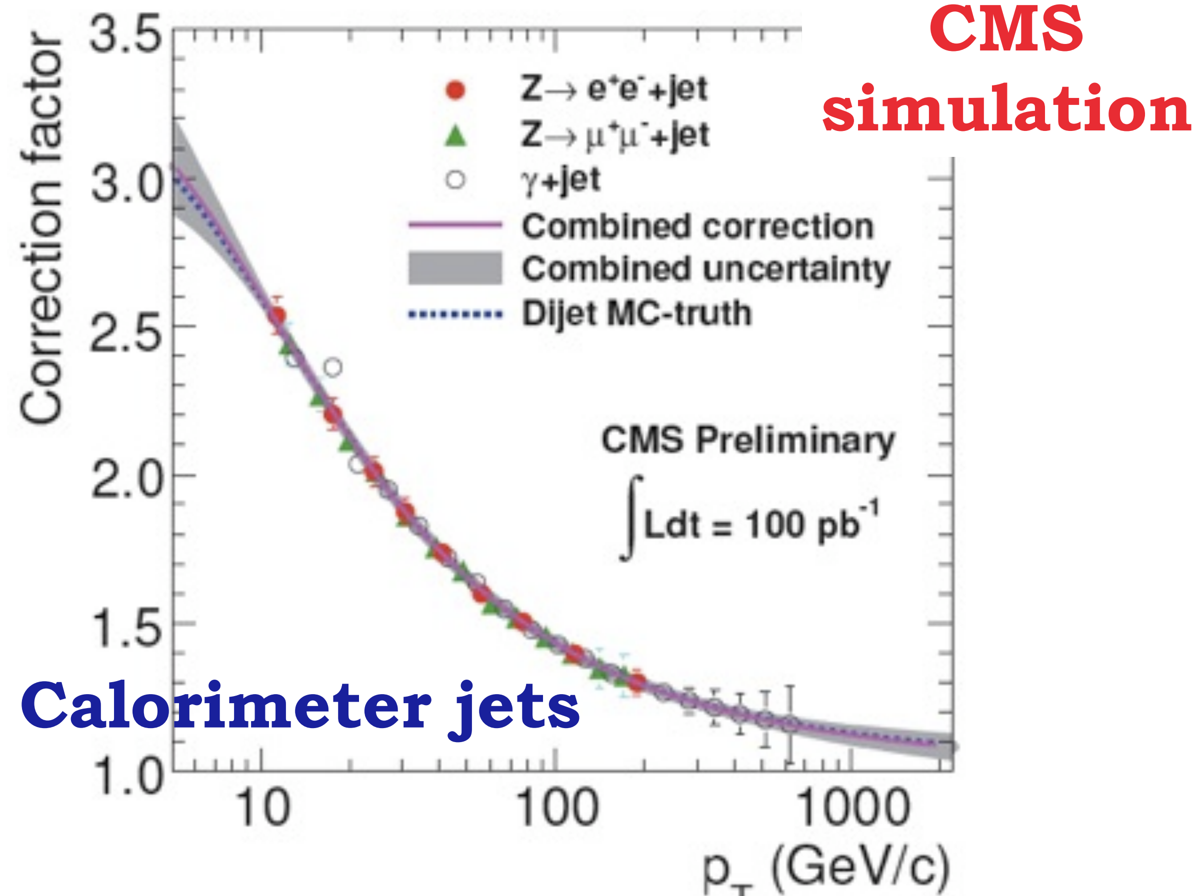




- ✦ Optimal utilization of the excellent tracker performance and the fine ECAL granularity for a global event reconstruction
- ✦ The particle flow algorithm reconstructs all the individual particles. Relevant for jets are:
  - charged hadrons (tracker +ECAL+HCAL signal compatibility)
  - photons (ECAL only)
  - neutral hadrons (HCAL only)
- ✦ Particle flow jets result after the clustering of reconstructed particles
- ✦ Excellent response and resolution for particle flow jets

Jet energy calibration





✦ The jet energy calibration is necessary due to the non-linear and non-uniform detector response

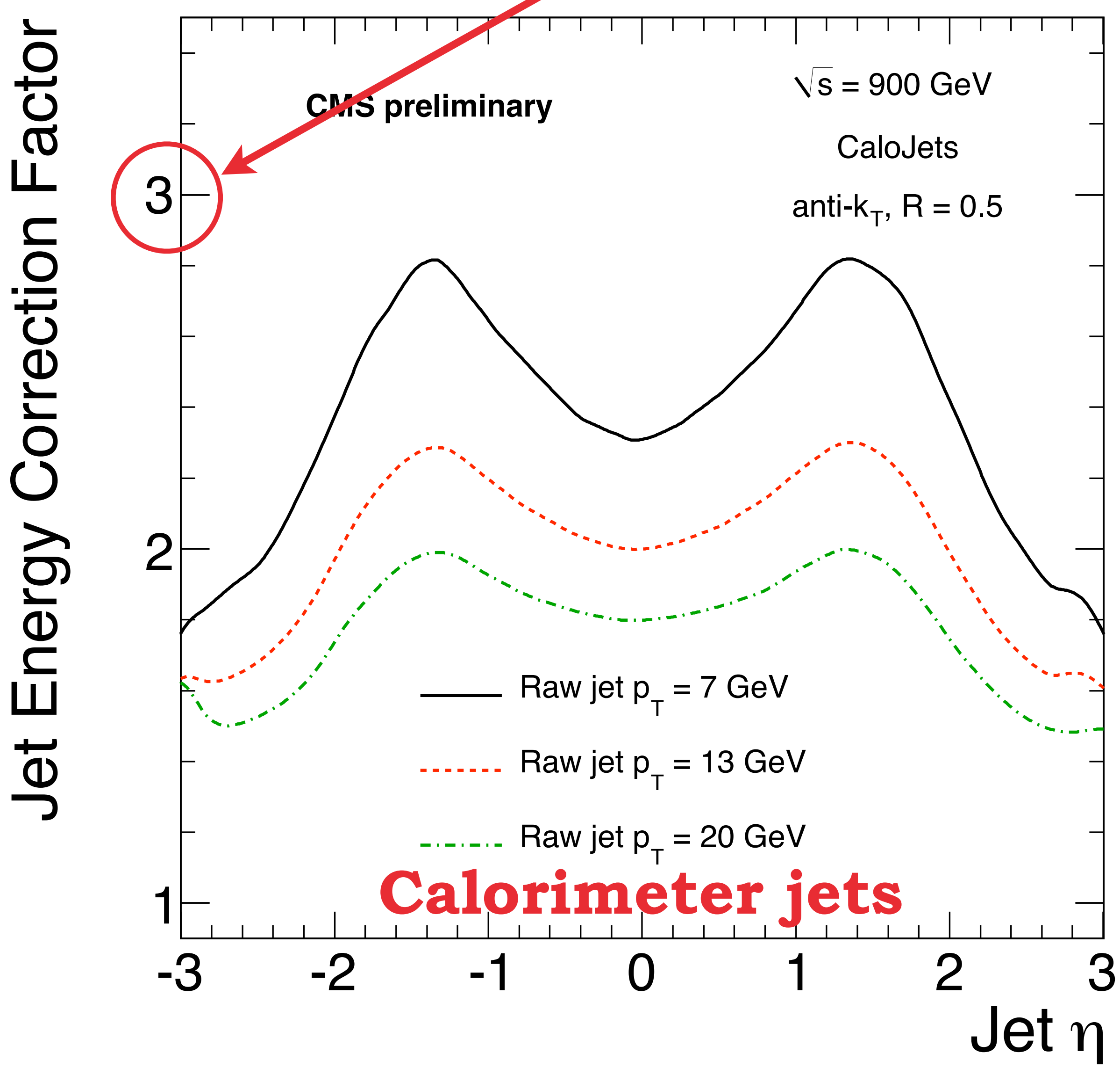
✦ CMS uses a multi-step approach for jet energy calibration. Each step addresses a specific effect:

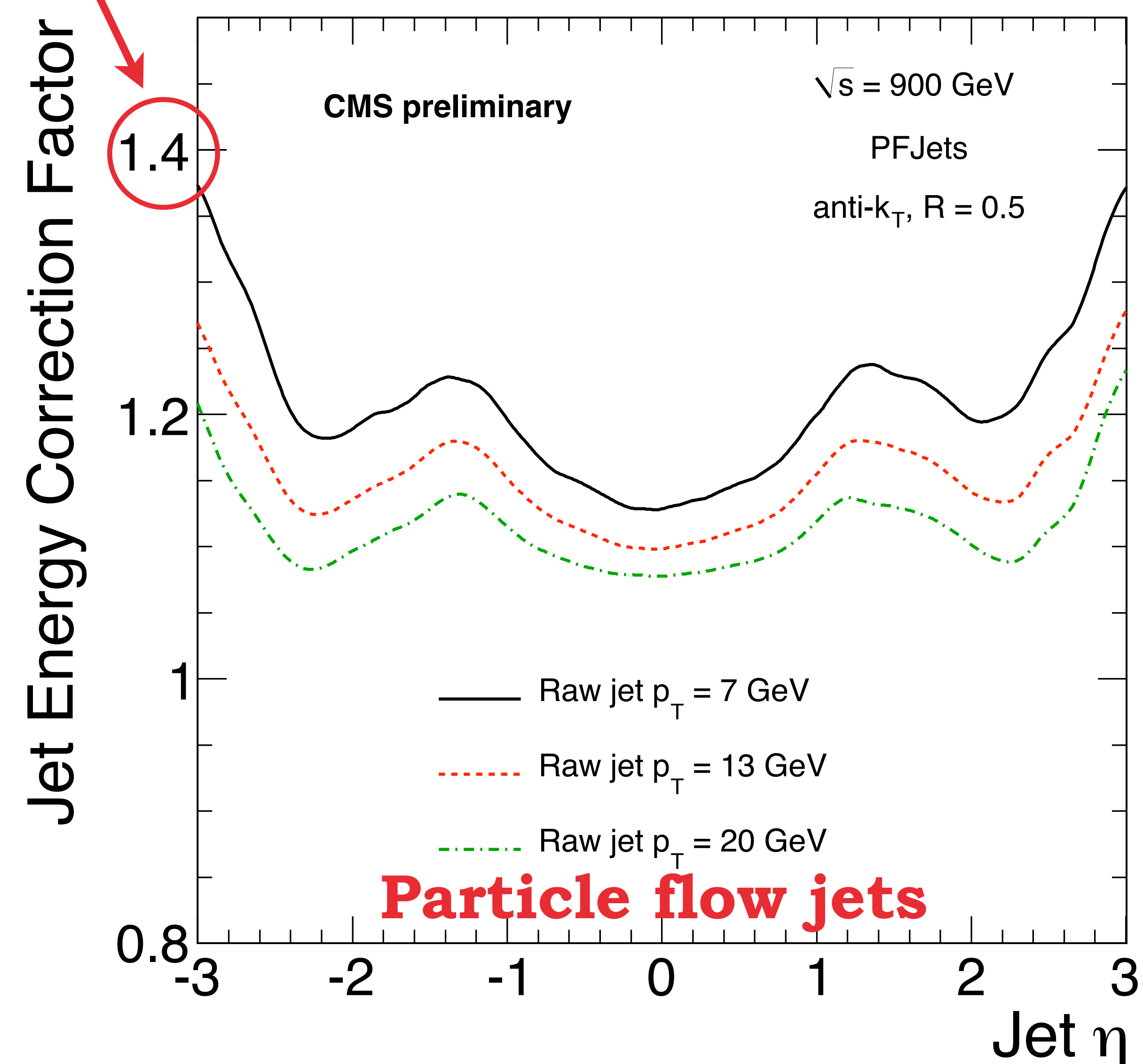
- Offset (removes the average energy due to noise and pile-up)
- Relative (removes the pseudorapidity dependence of the jet response)
- Absolute (restores the jet response to unity)

✦ CMS will determine the jet energy calibration with direct measurements from the data: dijet p_T balancing for the relative correction, γ/Z+jet p_T balancing for the absolute correction

Jet energy calibration @ 900 GeV

Notice the different scale !!!





- ✦ The jet energy calibration for the jet commissioning studies with 900 GeV and 2.36 TeV collisions is determined from Monte Carlo truth
- ✦ Jets observed in the first data sample are very soft and require large energy correction factors

The first pp collisions in CMS

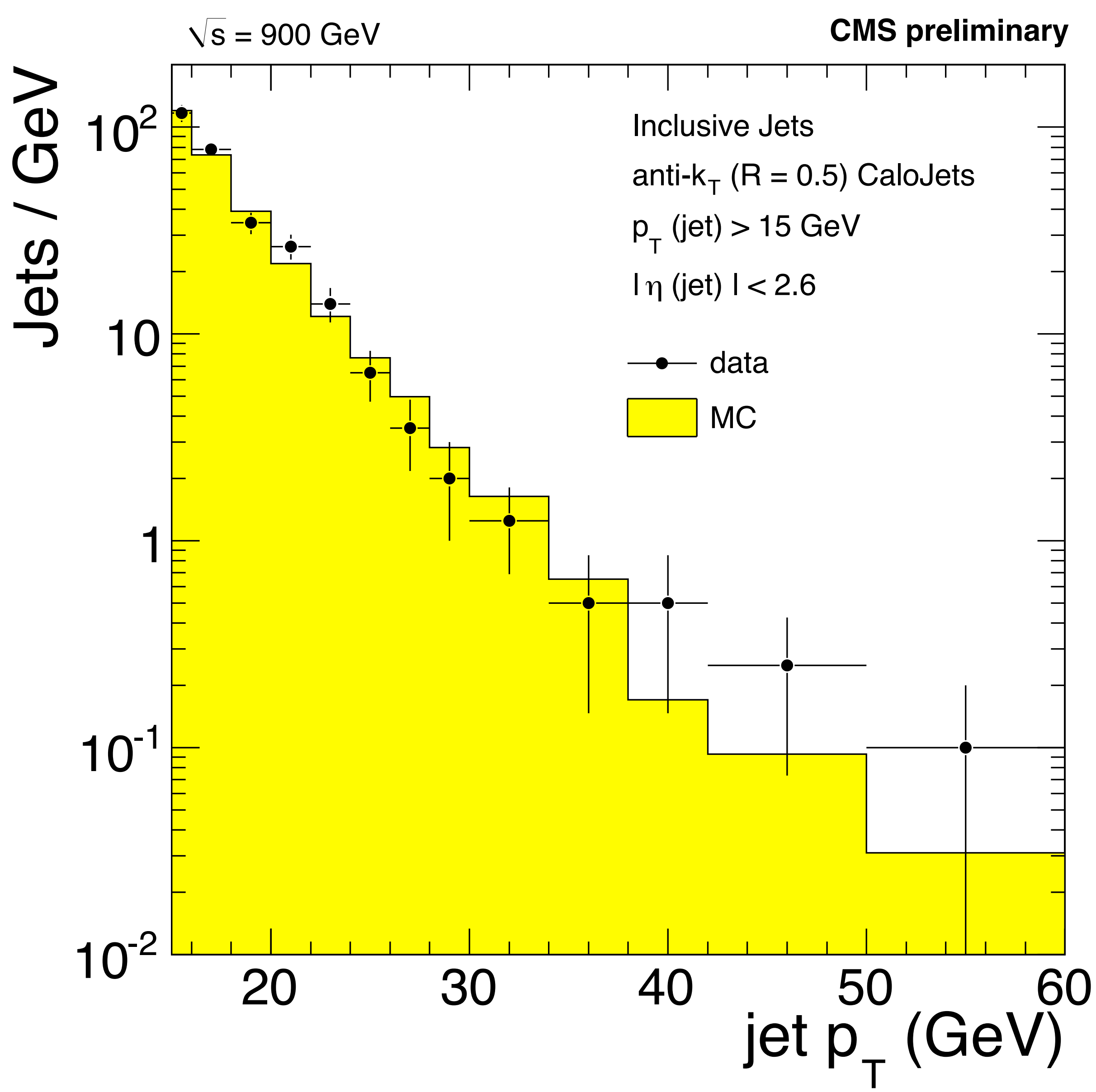
✦ **During its early commissioning phase, LHC delivered pp collisions at center of mass energies:**

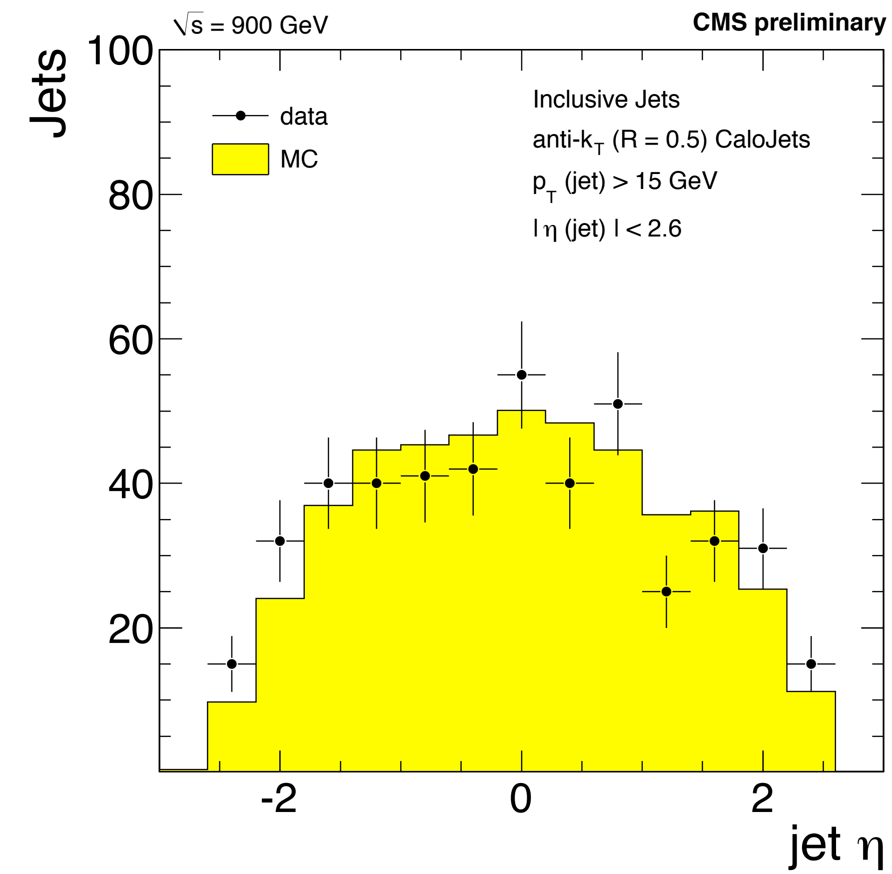
- 900 GeV (~350k minimum bias events, ~10μb^{-1})
- 2.36 TeV (~10k minimum bias events, <1μb^{-1})

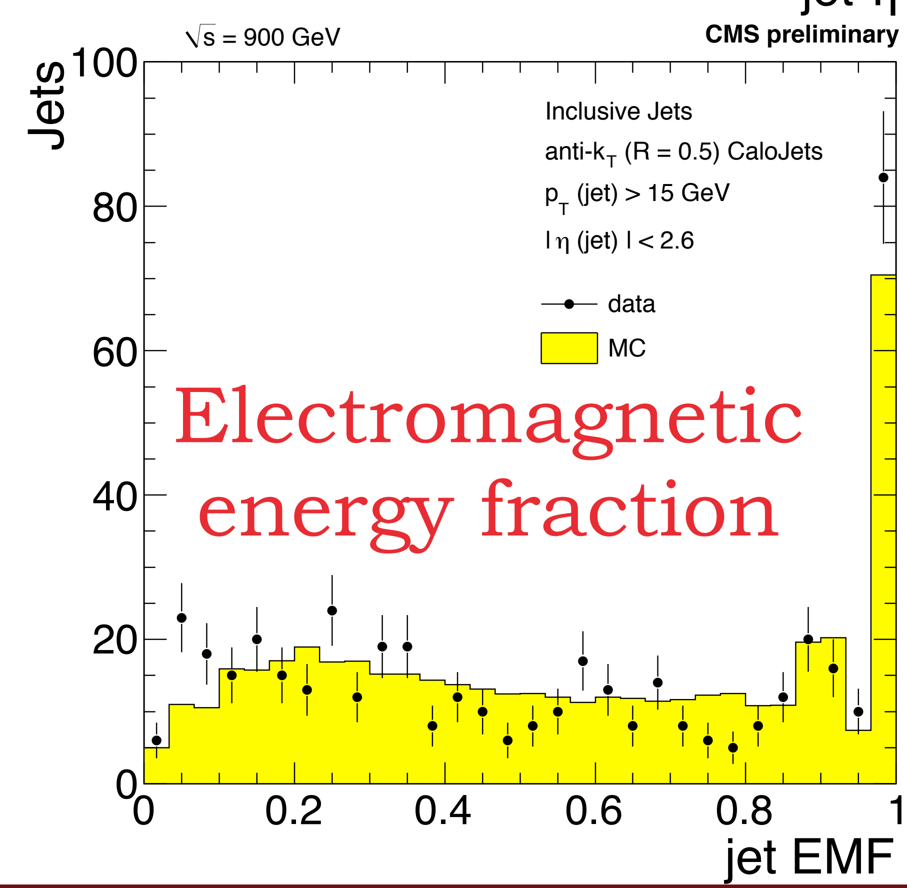
✦ **CMS operated smoothly and took good quality data:**

- more than 99% of detector channels operational
- high data taking efficiency (>80%)
- fast data access
- first Physics paper already published (*"Transverse momentum and pseudorapidity distributions of charged hadrons in pp collisions at sqrt(s) = 0.9 and 2.36 TeV"*-- *JHEP 02 (2010) 041*)

Jets from 900 GeV collisions (I)

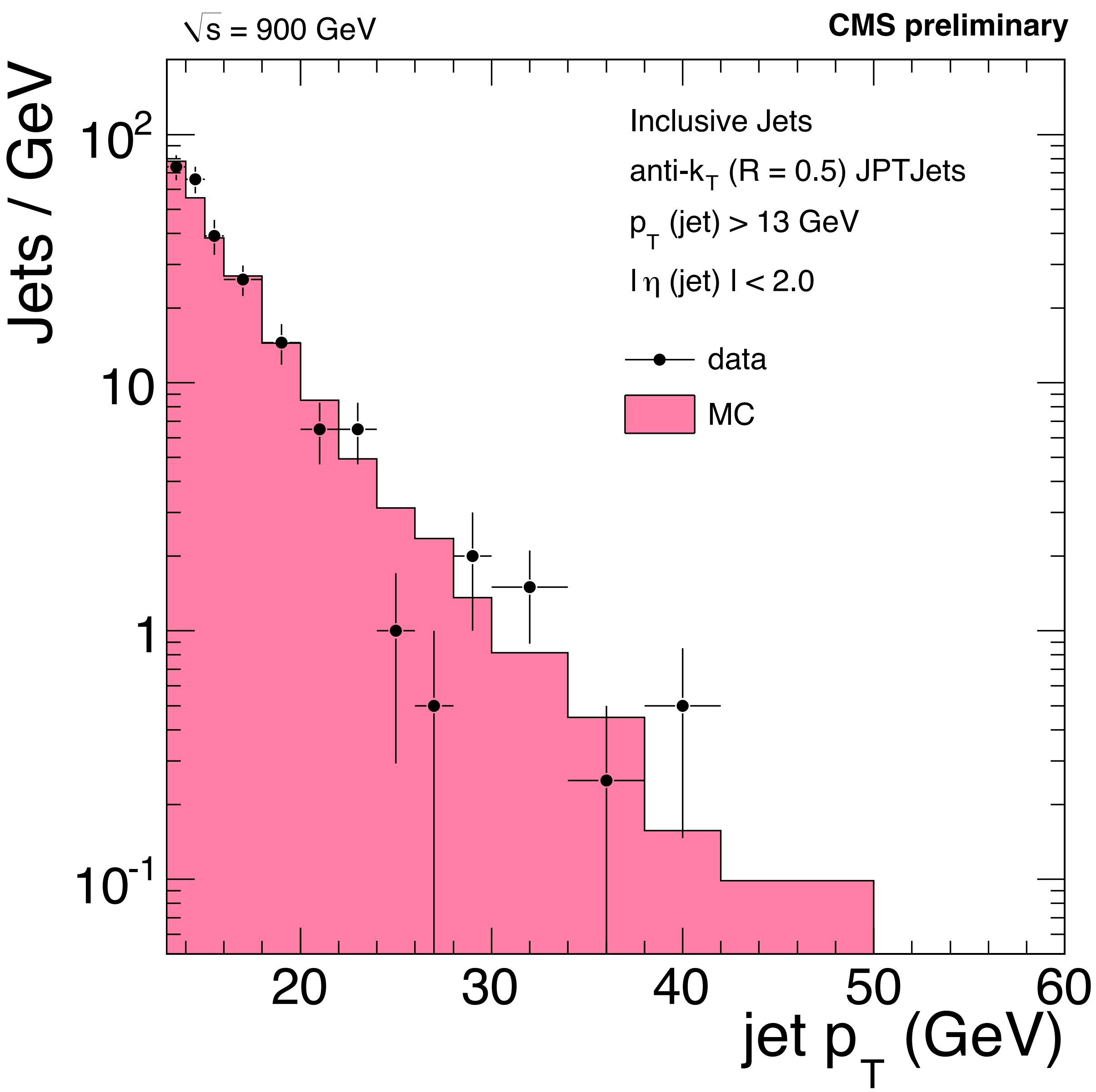


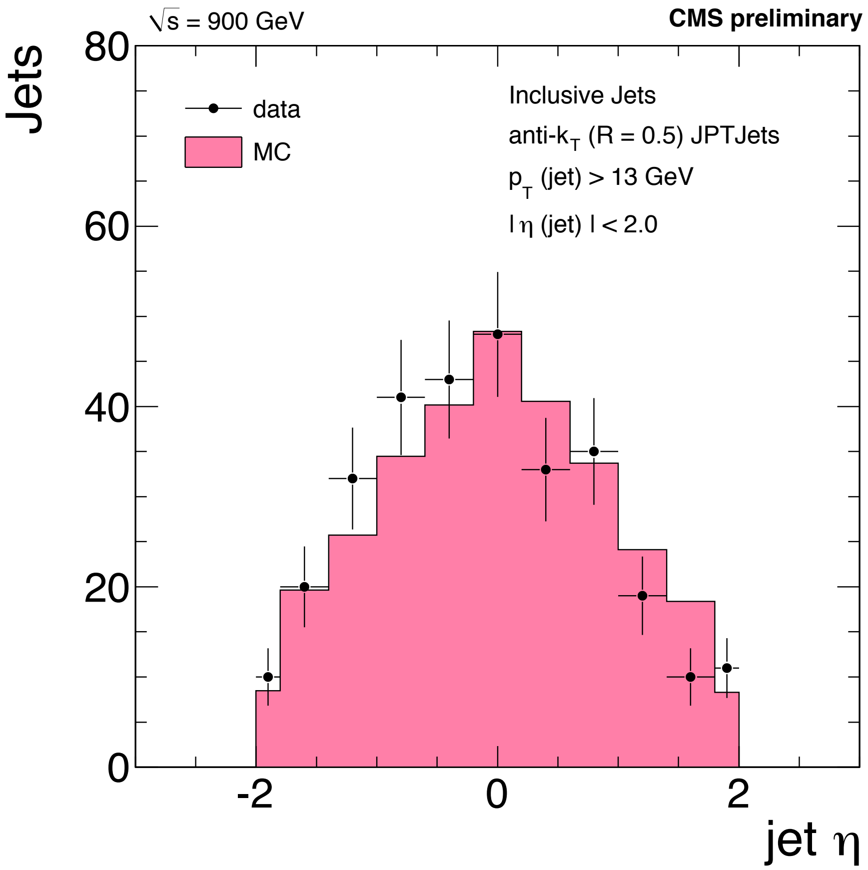


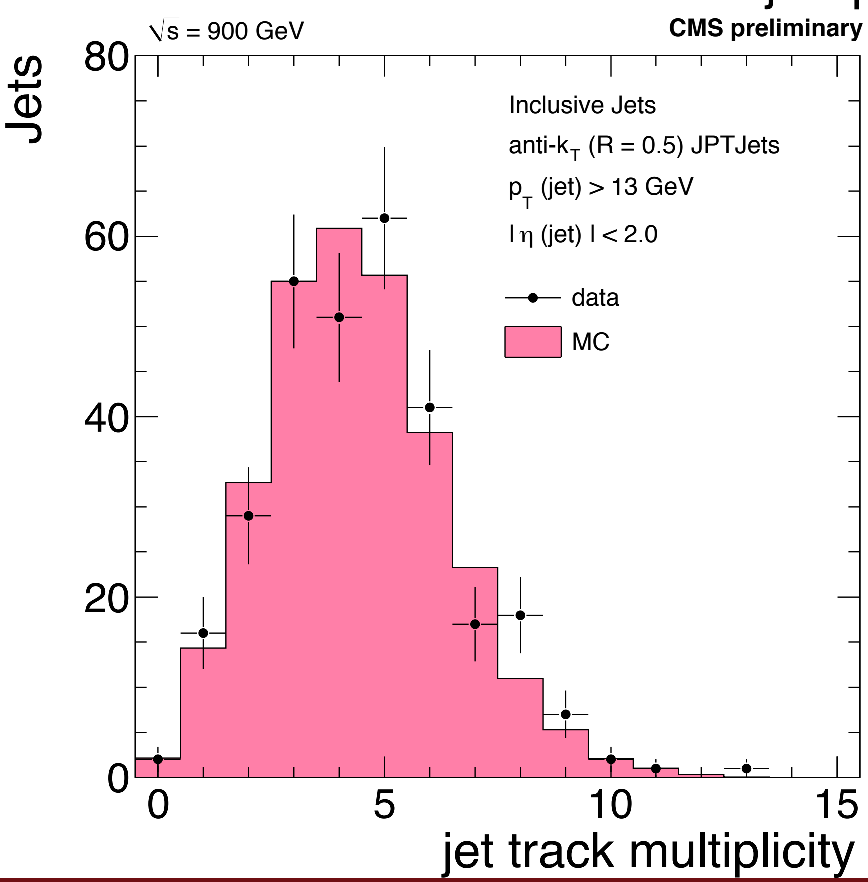


- ✦ **Inclusive calorimeter** jets after "tight" ID requirements to enhance purity
- ✦ 459 jets with p_T > 15 GeV and |η|<2.6
- ✦ Monte Carlo normalized to data
- ✦ Good agreement between MC and data in both kinematic and composition variables

Jets from 900 GeV collisions (II)

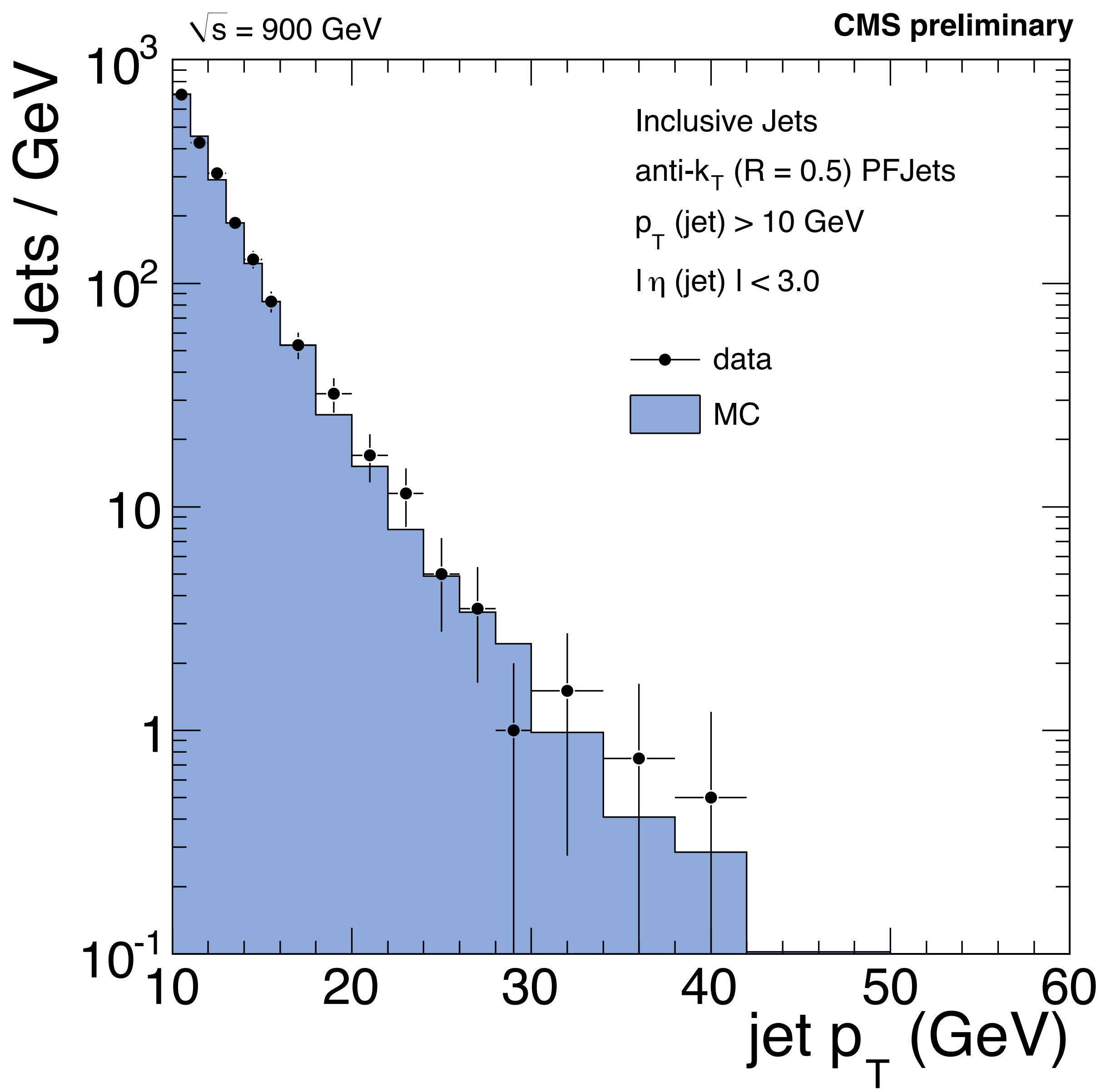


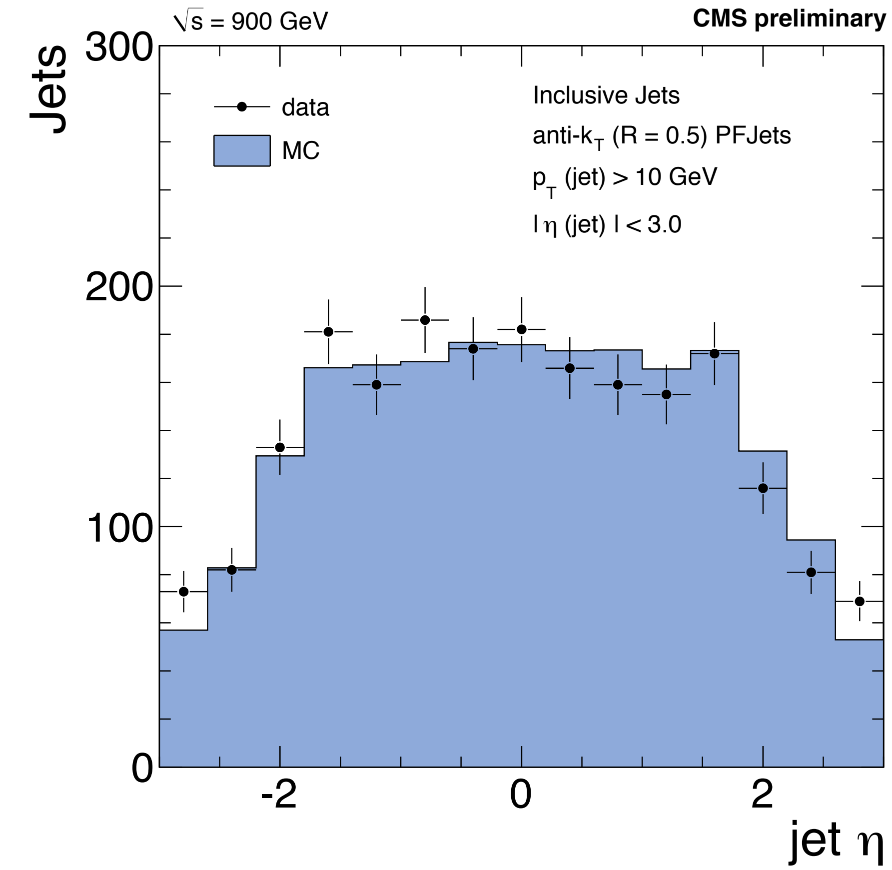


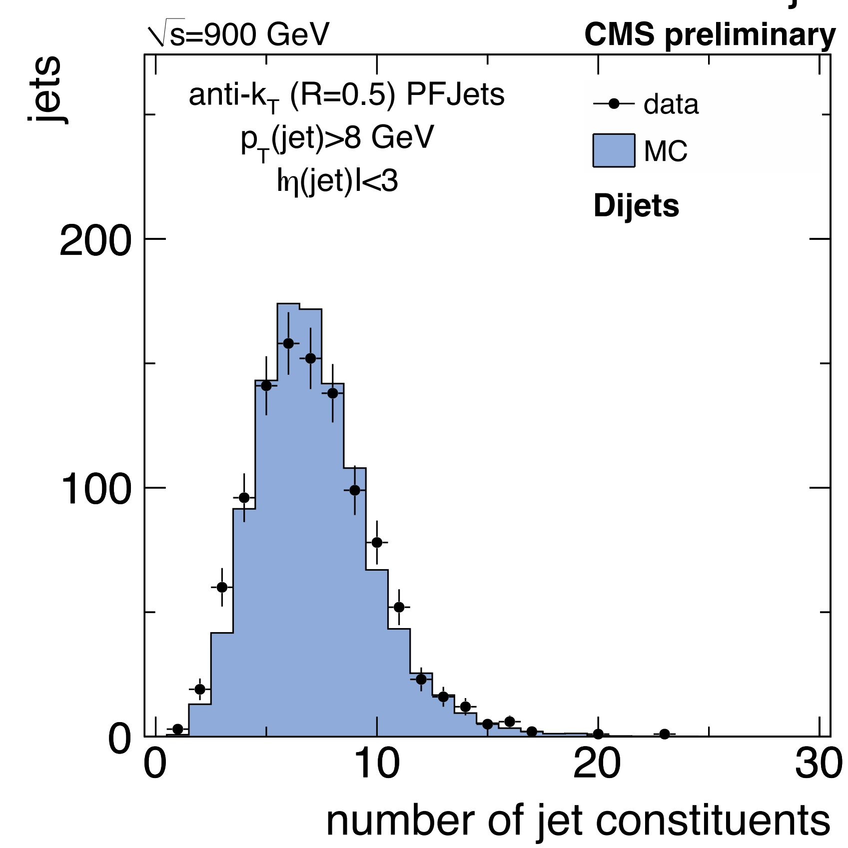


- ✦ **Inclusive jet-plus-tracks** jets after "tight" ID requirements to enhance purity
- ✦ 302 jets with p_T > 13 GeV and |η|<2.0
- ✦ Monte Carlo normalized to data
- ✦ Good agreement between MC and data in both kinematic and composition variables

Jets from 900 GeV collisions (III)

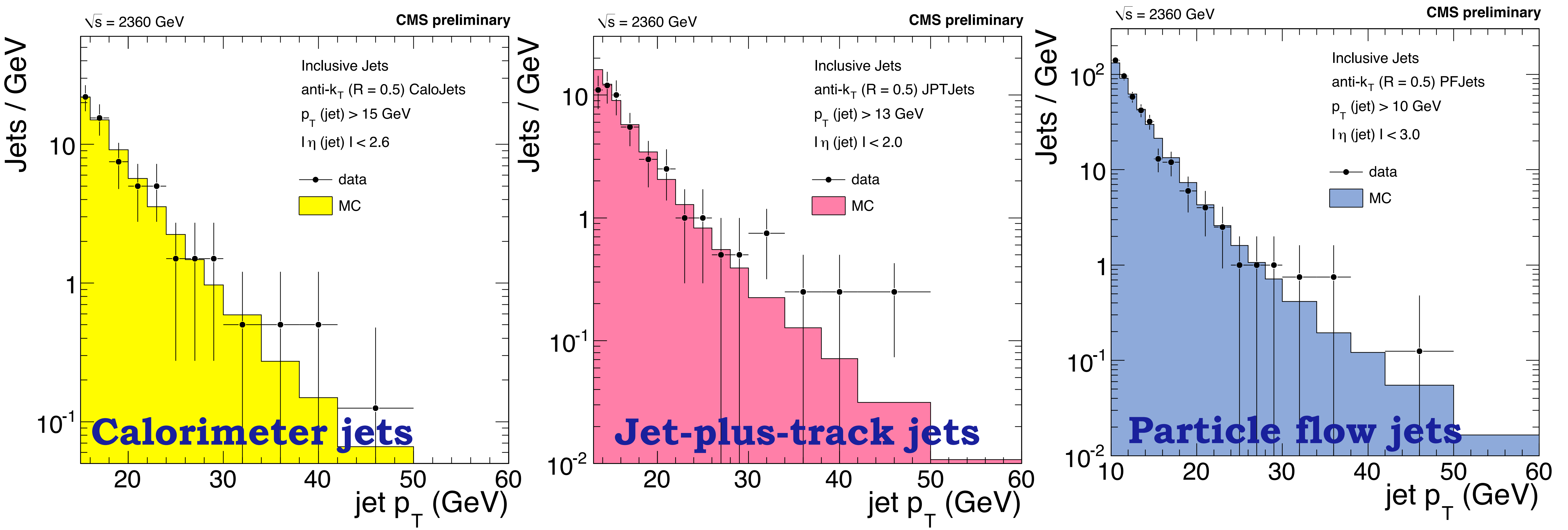






- ✦ **Inclusive particle flow** jets after "tight" ID requirements to enhance purity
- ✦ 2,088 jets with p_T > 10 GeV and $|\eta|<3.0$
- ✦ Monte Carlo normalized to data
- ✦ Good agreement between MC and data in both kinematic and composition variables

Jets from 2.36 TeV collisions

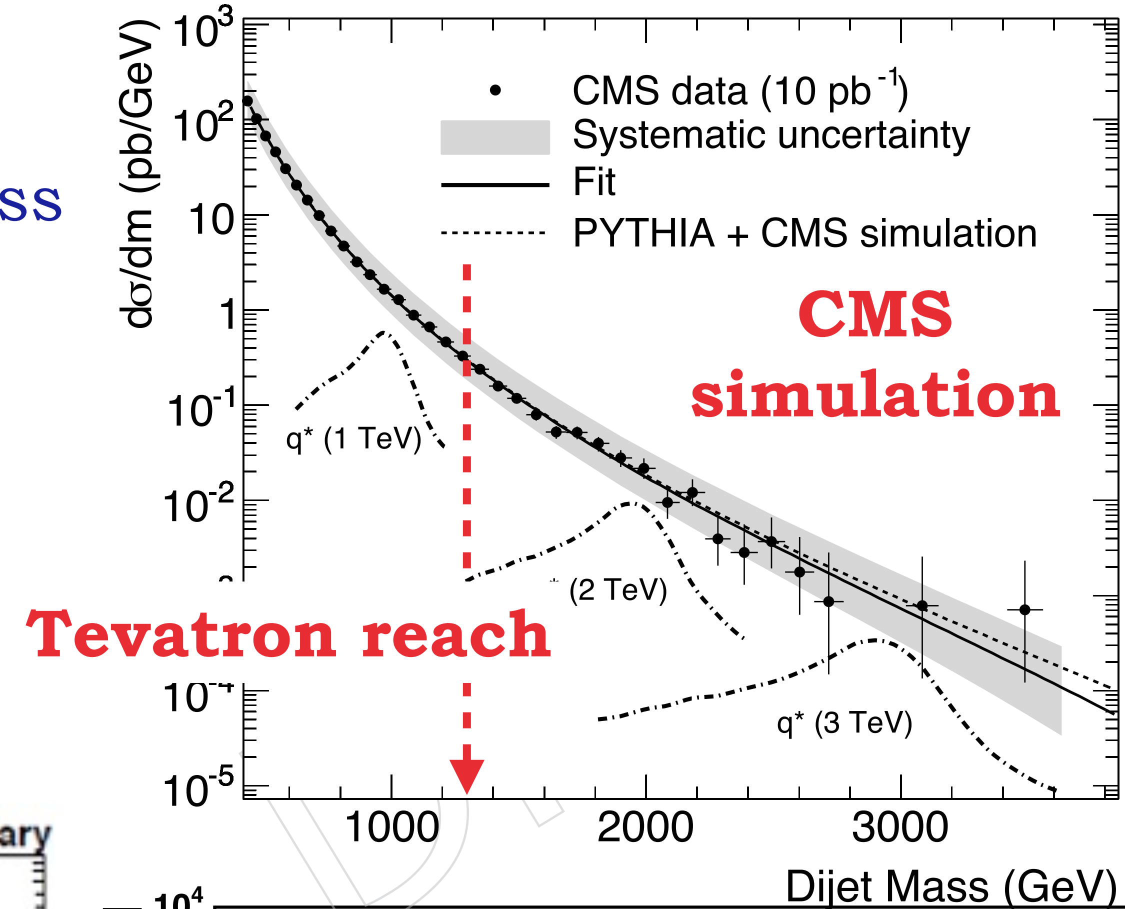


- **Inclusive** calorimeter, jet-plus-track and particle flow jets after "tight" ID requirements to enhance purity
- Monte Carlo normalized to data
- Good agreement between MC and data

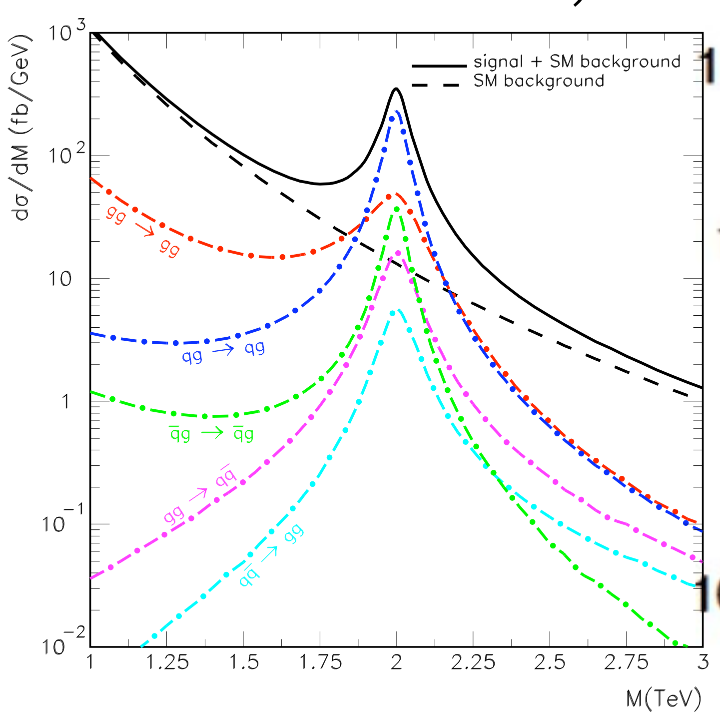
Early Physics prospects with jets

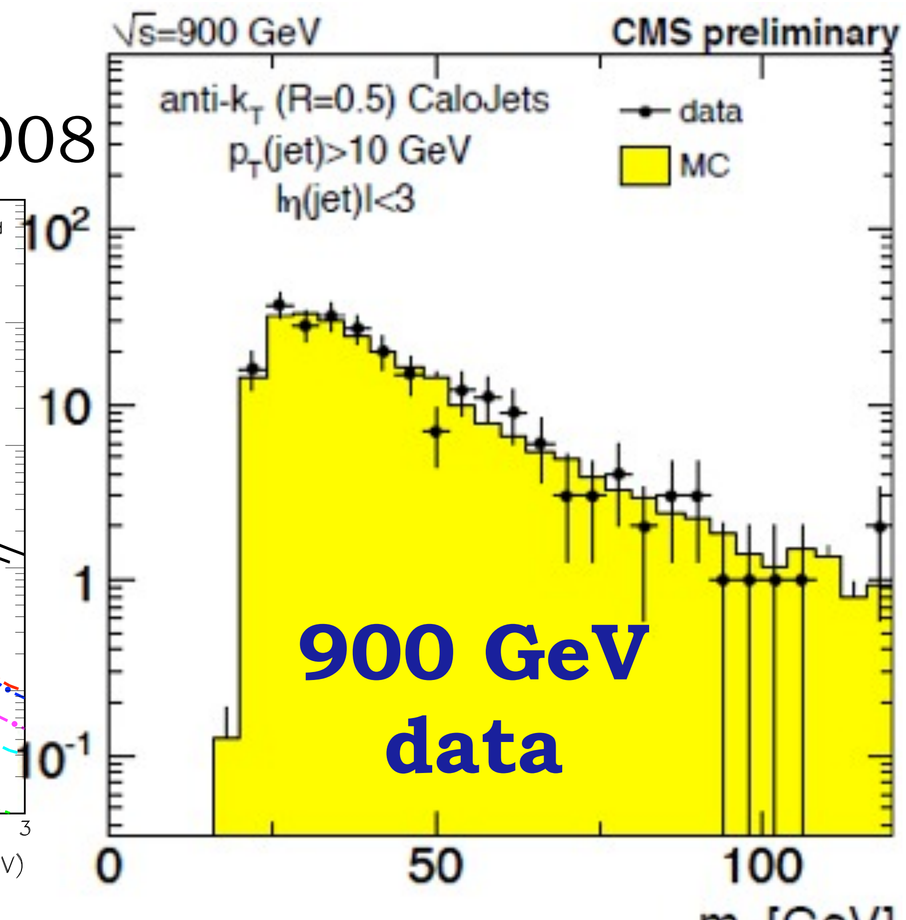
Dijet mass: search for narrow resonances

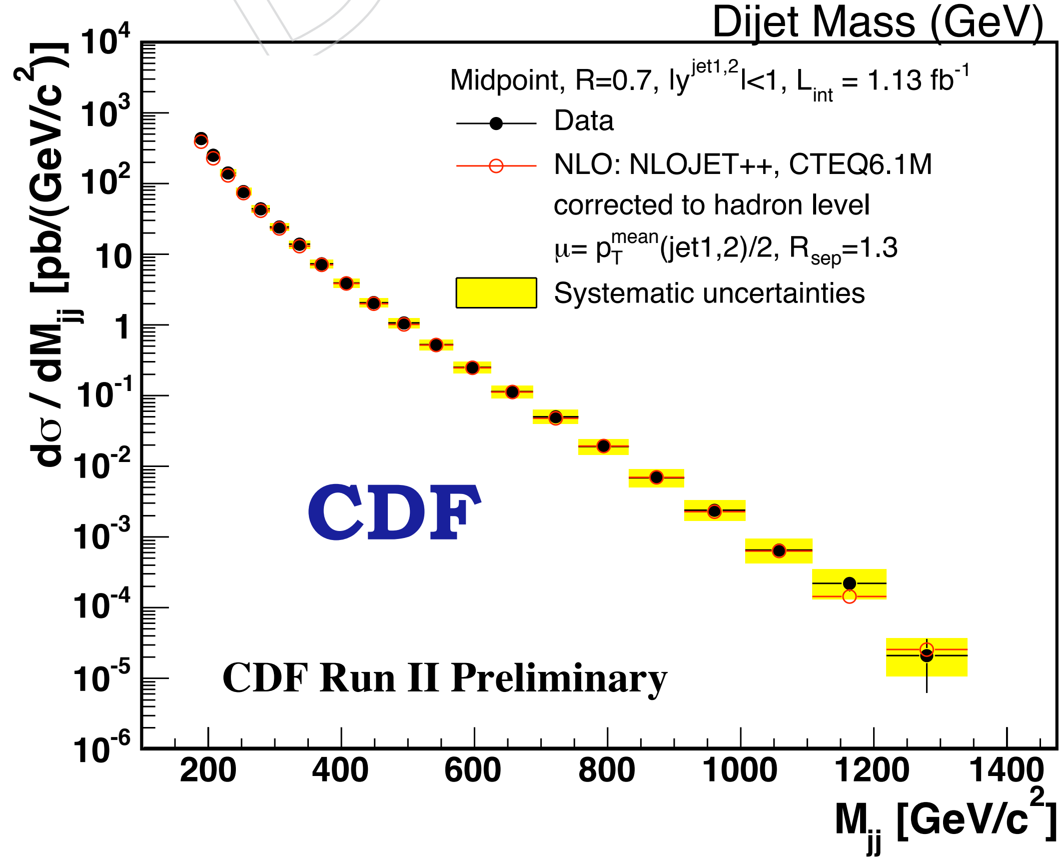
- ✦ A small amount (10 pb^{-1}) of data @ 7 TeV pp collisions will be enough to double the dijet mass reach of Tevatron
- ✦ Search for narrow resonances (low mass string resonances, axigluons, colorons, excited quarks, massive gravitons, etc)
- ✦ Confrontation of the pQCD predictions in a new kinematic regime



PRL 101:241803, 2008





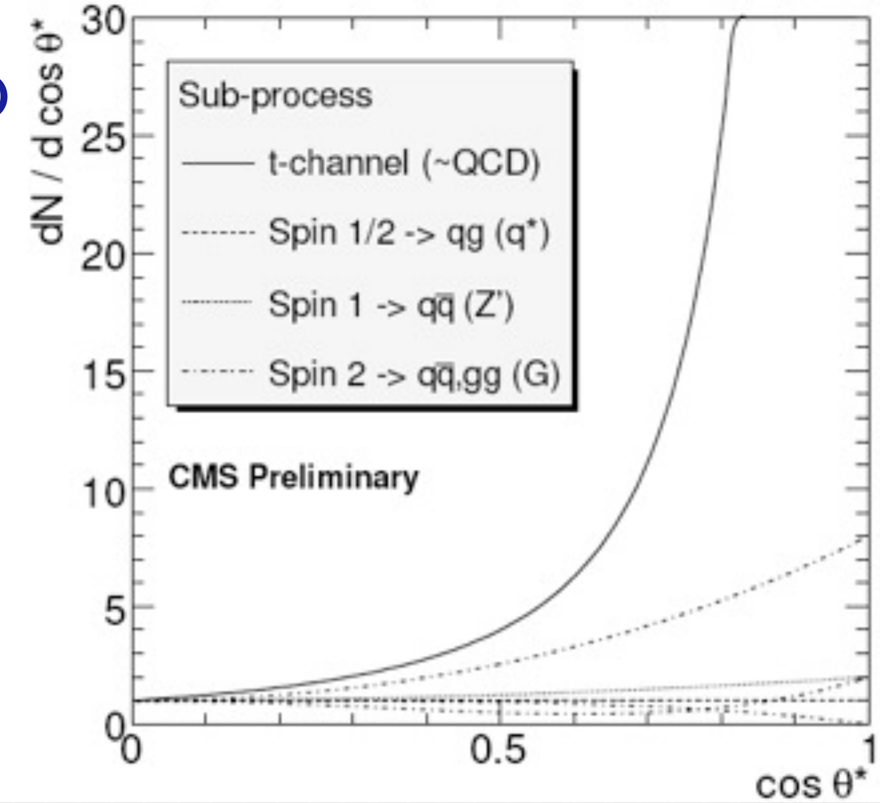


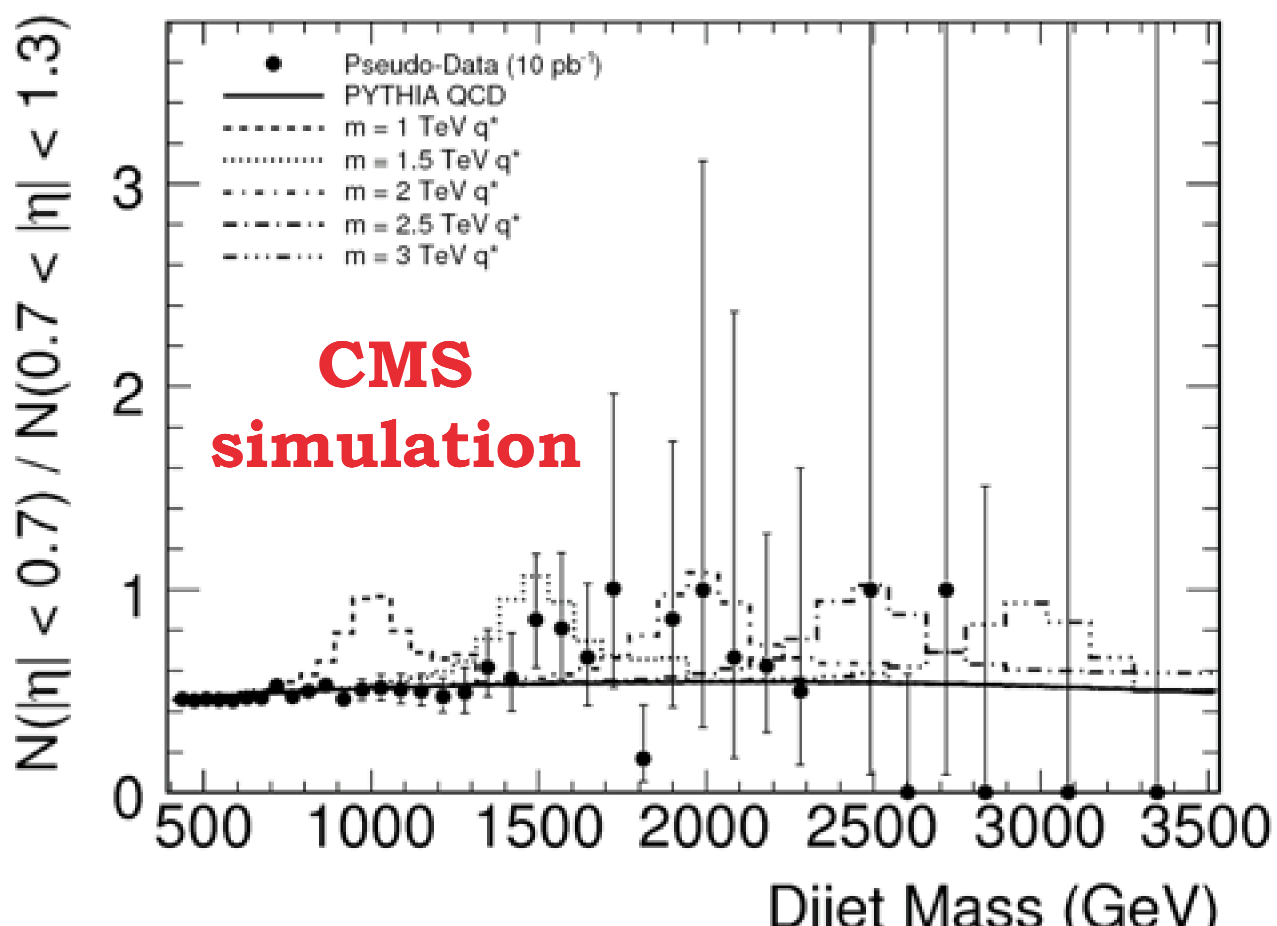
Dijet ratio

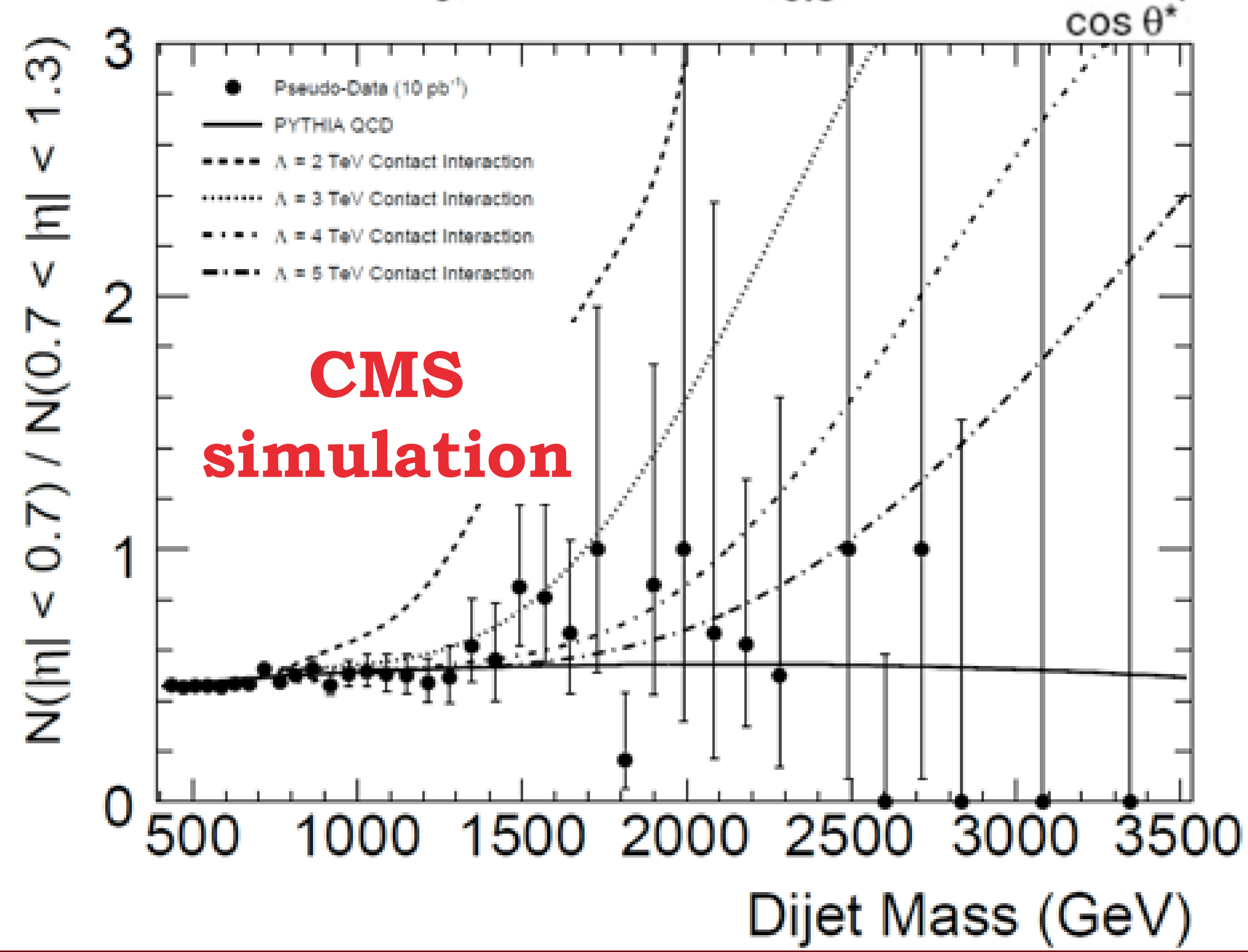
✦ The dijet angular distribution predicted by QCD is different from other processes leading to dijet production at high masses => sensitivity to new Physics (resonances, contact interactions)

✦ **Ratio of the number of dijets with |η|<0.7 over the number of dijets with 0.7<|η|<1.3**

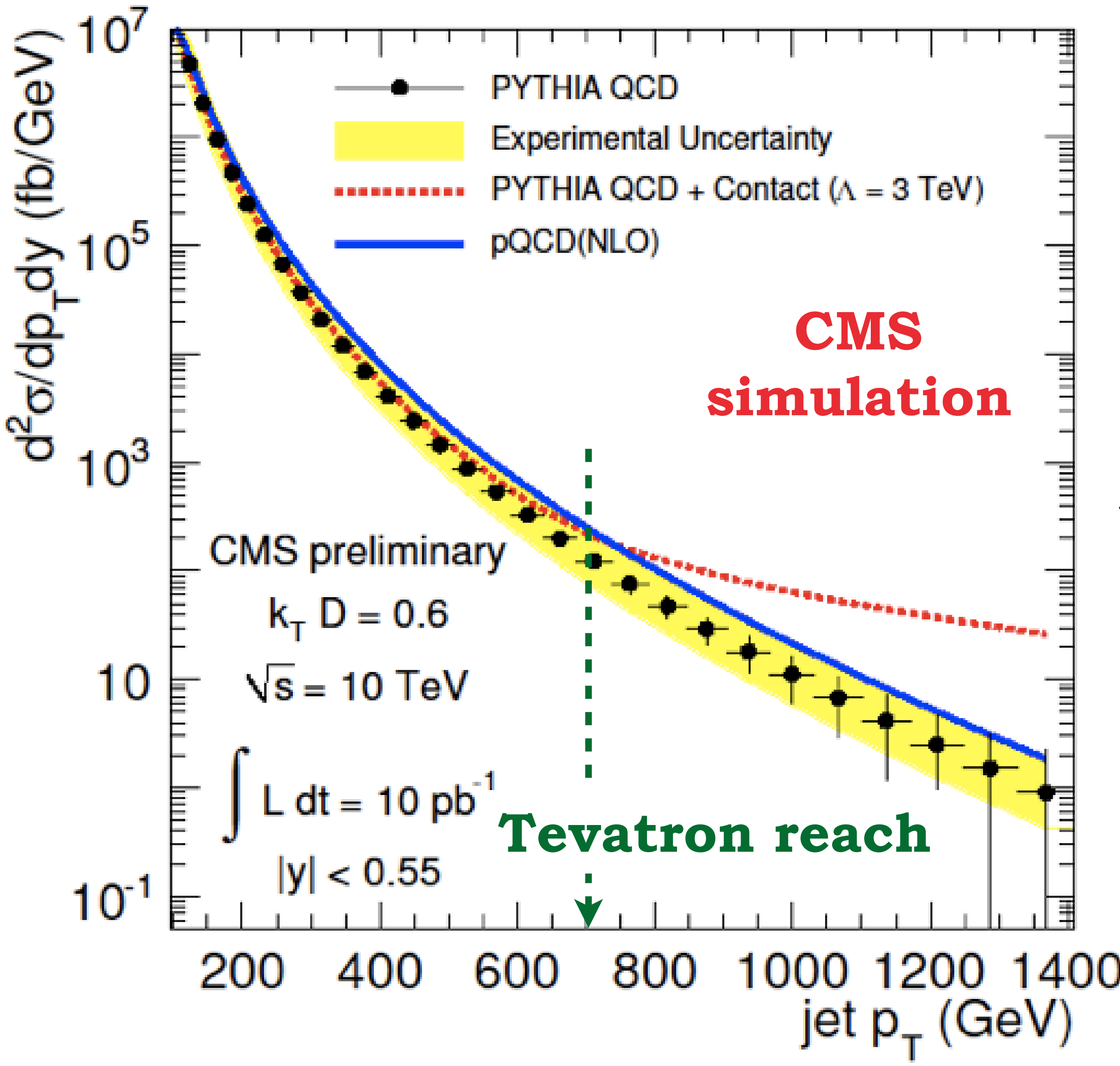
✦ Measurement insensitive to many experimental uncertainties (e.g. jet energy scale, luminosity)



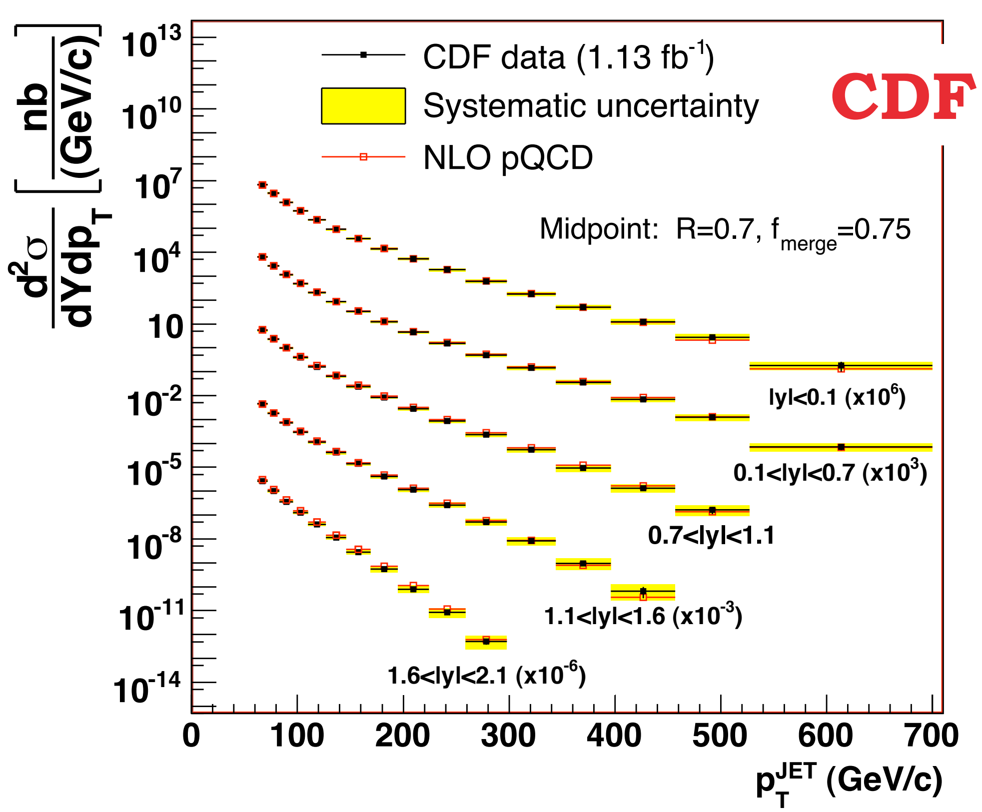




Inclusive jets



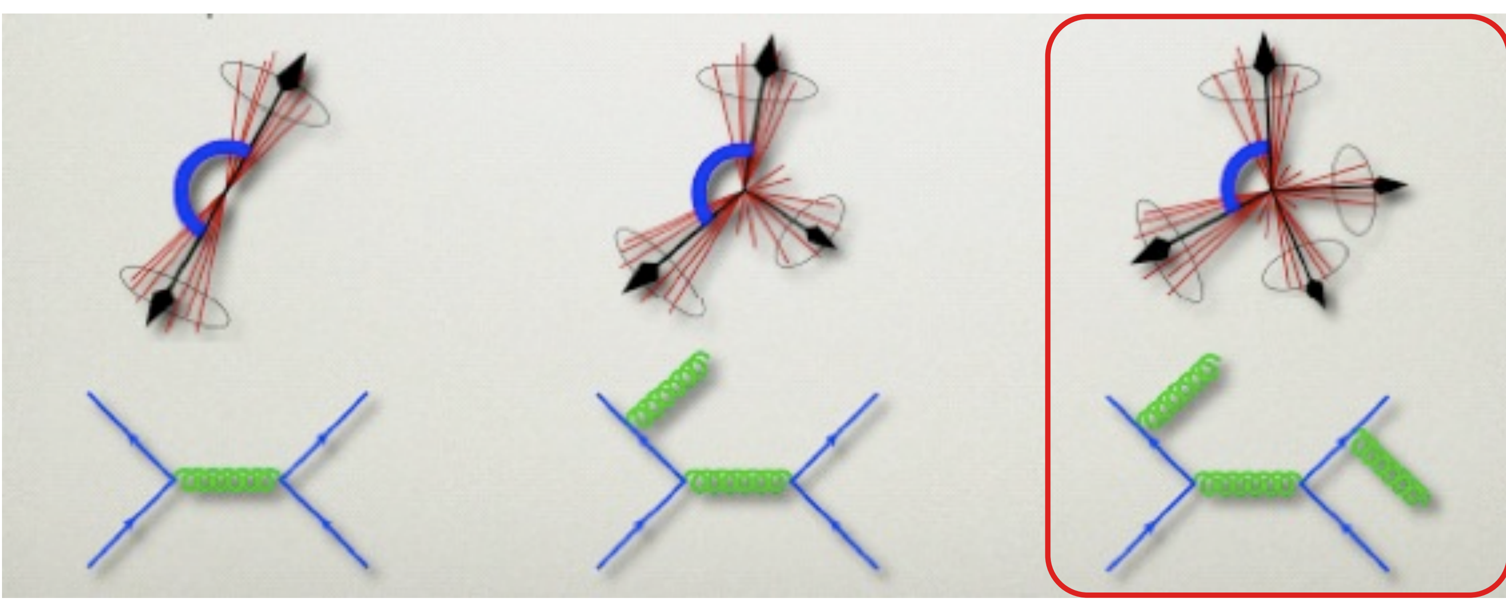
- ✦ The inclusive jet cross section is an important jet measurement:
  - direct confrontation of the QCD predictions in the TeV scale
  - sensitivity to new Physics
  - jet commissioning
- ✦ Affected by many experimental uncertainties (e.g. jet energy scale, jet energy resolution, luminosity)



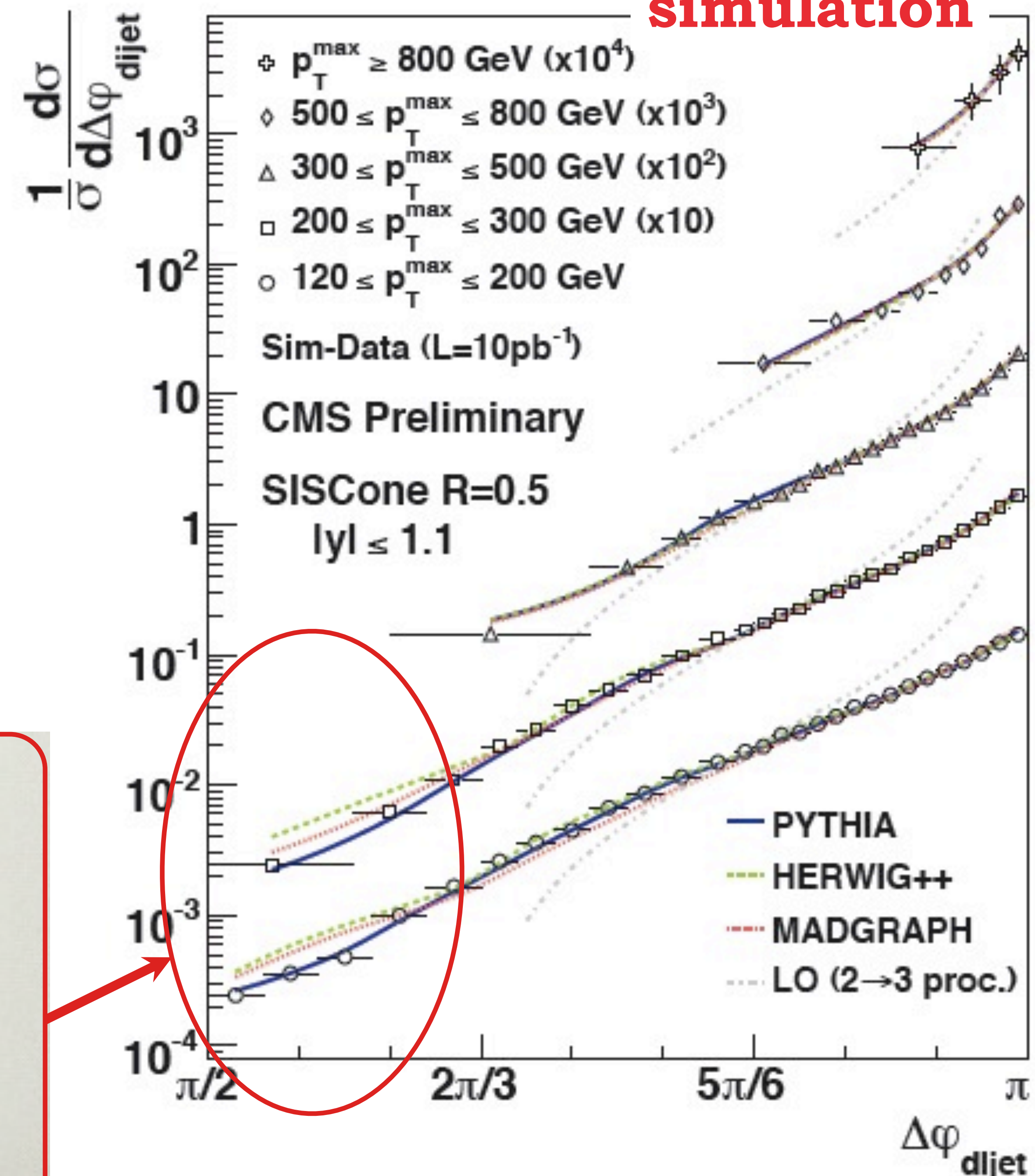
Azimuthal decorrelation

Observable: $\frac{1}{N}\frac{dN}{d\Delta\phi}$

✦ Measurement of the azimuthal angle between the two leading jets: **sensitive to radiation effects without explicitly measuring the radiated jets**
✦ Test of the pQCD calculations
✦ Sensitivity to multijet production and gluon radiation modeling
✦ Not affected by the major jet related uncertainties (JES)



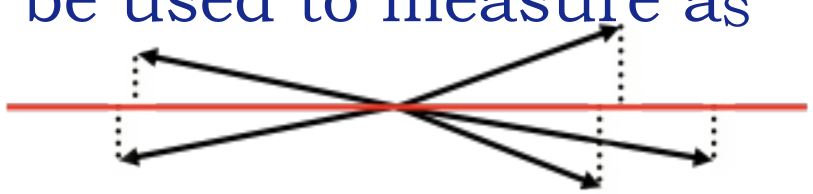
CMS simulation



Event shapes

Observable: $$\frac{1}{N}\frac{dN}{d\log\left(\tau_{\perp,C}\right)}$$

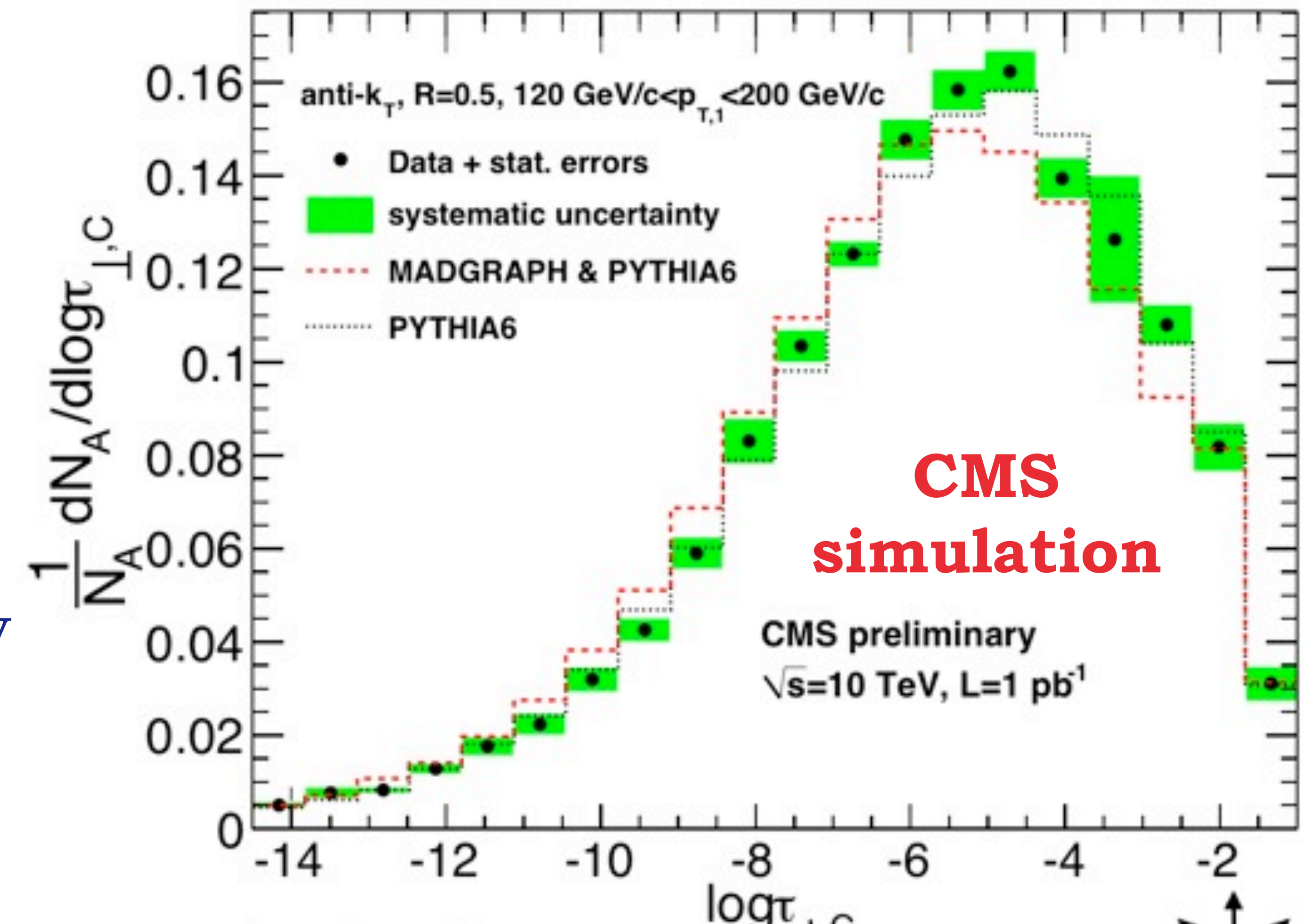
- Study of the kinematic variables (e.g ***central transverse thrust***) that probe the structure of the hadronic final state
- Test of QCD dynamics
- Not affected by the JES uncertainty
- Can help tune MC generators
- Can be used to measure α_S

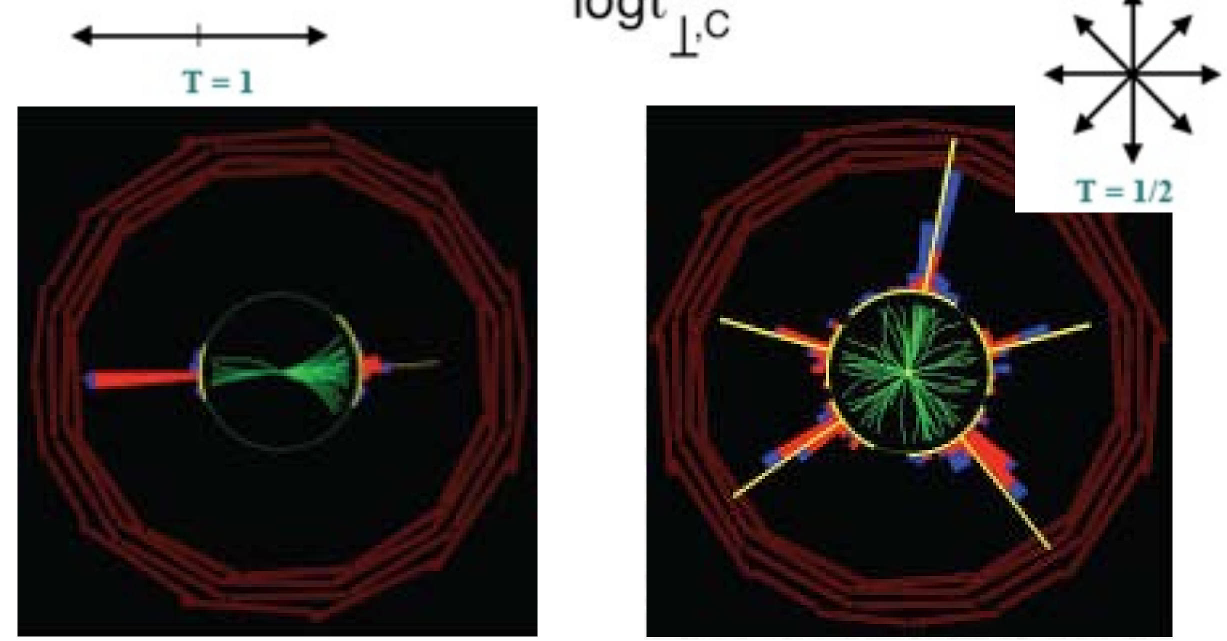


$$\tau_{\perp,C} \equiv 1 - T_{\perp,C}$$

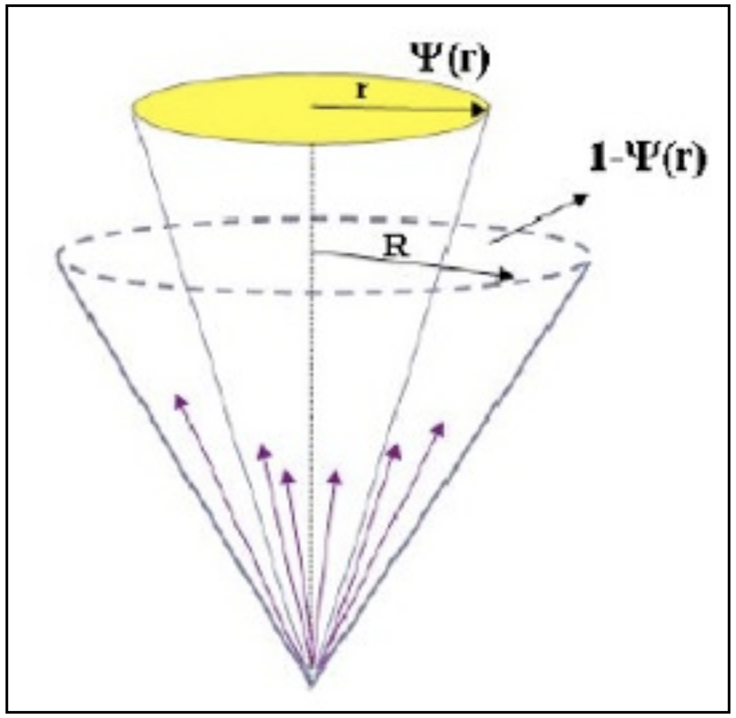
$$T_{\perp,C} \equiv \max_{\vec{\eta}_T} \frac{\sum_i \left|\vec{p}_{\perp,i} \bullet \vec{\eta}_T\right|}{\sum_i p_{\perp,i}}$$

T→1 for 2→2 process
T→1/2 for multijet events

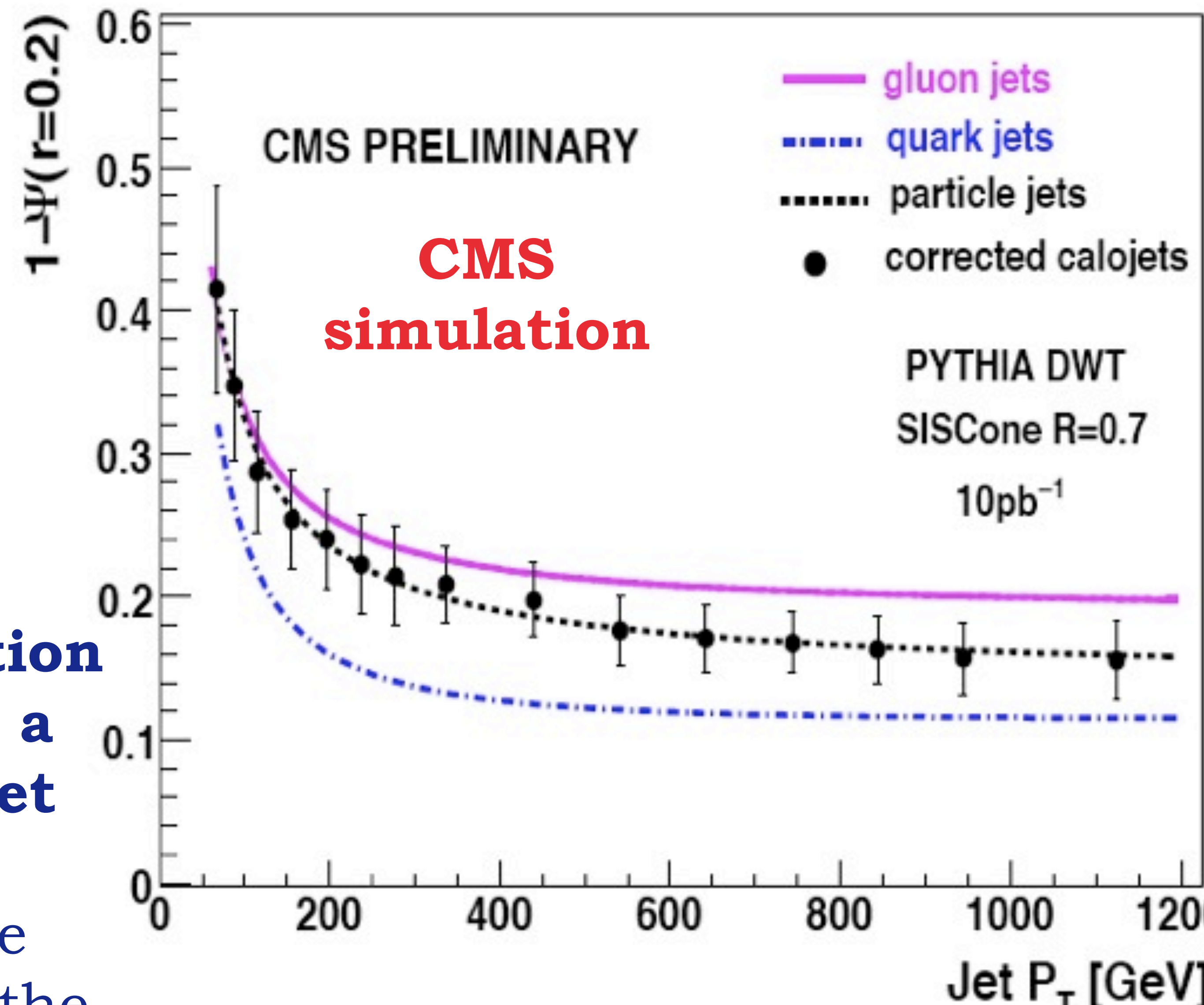




Jet shapes



Observable: $\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{p_T(0,r)}{p_T(0,R)}$



- ✦ Measurement of the energy profile inside jets
- ✦ Integrated jet shape: **average fraction of jet transverse momentum inside a cone of radius r concentric to the jet axis**
- ✦ Jet structure measurements can be used to test the showering models in the MC generators
- ✦ Can be used to distinguish gluon originated jets from quark jets

Quark jets are narrower than gluon jets ⇒ sensitivity to quark-gluon fraction

Summary

✦ Jets are the most frequently produced objects in hadron colliders. Their understanding is essential for the LHC experiments.

✦ CMS has developed multiple techniques to reconstruct jets in an attempt to use optimally the various sub-detectors.

✦ Jet performance studies with the first pp collisions recorded by CMS at 900 GeV and 2.36 TeV indicate good agreement between data and Monte Carlo, in the low p_T regime, for all jet types.

✦ The much higher center of mass collision energy at LHC with respect to Tevatron, allows the exploration of the TeV scale with a small amount of data: 10-100 pb^{-1} is sufficient to double or triple the jet p_T reach.

✦ CMS has a very rich program of jet measurements to confront the QCD predictions and search for new Physics.